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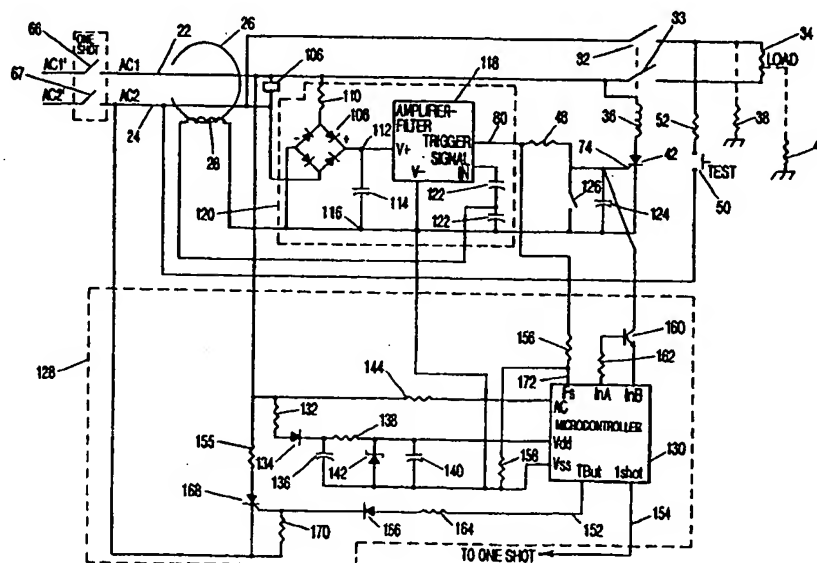
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(54) Title: FAIL SAFE FAULT INTERRUPTER



(57) Abstract: An electronic test circuit (128) for the self-testing of fault detection devices such as GFCI's, AFCI's and RCD's that enhances the safety of such devices by automatically testing the function of all components of these detection components without the need for manual intervention. This self-test device (128) tests the functioning of the primary circuit breaker (32, 33) and detects failure modes such as welded contacts in the circuit breaker (32, 33). By using a secondary, "one-shot" circuit breaker (66, 67), power may be safely and automatically removed from a malfunctioning fault detection device, rendering it safe.

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## FAIL SAFE FAULT INTERRUPTER

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of the filing of U.S. Patent Application Serial No. 09/320,951, entitled "Fail Safe Fault Interrupter", filed on May 27, 1999, and the specification thereof is incorporated herein by reference.

### BACKGROUND OF THE INVENTION

#### 1. FIELD OF THE INVENTION

This invention relates to an electronic test circuit that attaches to a ground fault and/or arc fault interrupt device and automatically checks for the proper functioning of the ground fault and/or arc fault interrupt device, without the need for user attention, and disables the ground fault or arc fault interrupt device in a safe condition in case of a malfunction of the device.

#### 2. BACKGROUND OF THE INVENTION

A common source of electrical injuries in the home occurs when people place radios or similar electrical devices that are operated using household AC electrical current near a swimming pool or bathtub while swimming or bathing. For example, if an AC operated radio is knocked into water, it can create undesirable electrical leakage current through the water to ground creating what is known as a ground fault. A ground fault can also occur when a person touches an electrically hot conductor while standing on or touching a grounded conductive surface. When sufficient electrical current passes through a person, electrical burns or electrocution may result. Many electrical appliances such as heaters, hair dryers, electric razors and pumps are used near water and can present this type of hazard. Outdoor appliances such as power drills and electrically powered lawn care equipment are often subject to cut or frayed power cords that can present an electrical leakage hazard. Even a relatively low level of electrical current leakage can be dangerous to a human. Underwriters Laboratories, in their 943 standard for ground fault interrupt devices, requires that listed devices must open in response to any leakage current exceeding six milliamperes for class A devices

and 20 mA for class B devices.

A ground fault is not the only class of potentially dangerous abnormal operating conditions. Another type of undesirable operating condition occurs when an electrical spark jumps between two conductors or from one conductor to ground. This spark represents an electrical discharge through the air and is objectionable because heat is produced as a byproduct of this unintentional "arcing" path. Such arcing faults are a leading cause of electrical fires. Arcing faults can occur in the same places that ground faults can occur – in fact, a ground fault would be called an arcing fault if it resulted in an electrical discharge, or spark, across an air gap. Arc fault detection is typically accomplished by monitoring the electrical current flow into a load and comparing the profile of this current flow to a characteristic "signature" that arcing faults will exhibit.

In the United States, protection circuits known as ground fault current interrupters or GFCI's, are presently required by code for the bathrooms of most new homes and commercial buildings, as well as for garage and outdoor outlets in residential applications. In Europe, a similar device called a residual current detector, or RCD, is used for detecting and interrupting dangerous electrical leakage to ground. The theory of operation behind commercial GFCIs and RCDs is the same. The major difference between the two devices is that in the U.S., most GFCIs are required to trip when leakage currents exceed 6 milliamperes while European RCDs are generally set for a trip level of 15-30 milliamperes.

In commercial GFCI circuits, the current carrying conductors that connect the AC source to the load will pass through a current transformer, thereby acting as primary windings for that transformer. The transformer has a secondary winding with many turns coupled to an amplifier. In a two wire system, when no electrical leakage path to ground is present, all of the electrical current that goes out one wire returns in the other wire. Accordingly, the two currents, forward and reverse, balance out one another in terms of the magnetic flux that is generated in the current transformer and so no signal is generated in the transformer secondary. On the other hand, if there is leakage to

ground at the load or from the conductors connecting the source to the load, then there will be an imbalance in the currents. In other words, more electrical current goes out one wire than returns in the other, the difference being the component of current that takes another path (the ground fault current). This results in a net magnetic flux in the transformer and this will serve to generate an induced voltage in the secondary of the transformer. That secondary voltage is amplified, filtered, and used to trip a relay or circuit breaker, thus removing power from the load and removing power from the leakage path. Most GFCI circuits include a reset actuator that allows the circuit breaker to be reset. Most GFCI circuits include a test button that implements an artificial leakage path around the current transformer, allowing a user to manually test the GFCI circuit, by pressing the test button and confirming operation if the internal breaker appears to open. This test does not actually confirm that an internal breaker has opened. Usually, a reset button that is mechanically connected to the relay contacts pops out and the user must assume that this means that the circuit breaker opened and the GFCI is functional.

15 All of the above comments also apply to GFCIs and RCDs that are used for multiphase systems having more than two current carrying wires. The only difference is that the additional current carrying wires are also passed through the current transformer so that in the absence of an electrical leakage path, the currents going through the transformer sum to zero.

20 In many electrical systems, one of the current carrying conductors will be grounded at some point in the electrical system. This grounded conductor is known as the "neutral" conductor. GFCI's will often have a circuit to detect electrical leakages from this conductor to ground by means of a second current transformer. Typically, neutral to ground faults are detected by injecting a signal onto the neutral conductor which produces an oscillation if feedback is provided through the loop completed by the neutral to ground fault.

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In the United States, the National Electric Code has mandated that Arc Fault Current Interrupters, or AFCI's, be installed in certain new construction starting in the year 2002. The

requirements of AFCI circuits are under development under the Underwriters Laboratories standard 1699. That standard will require that AFCI's be provided with a test circuit that simulates the arc detection circuitry output to exercise the remaining portions of the device. Since in most implementations, the AFCI will be combined with a GFCI and share much of the detection and interruption electronics, the use of a single test button for manual testing of both ground fault detection and arc fault detection will probably be common.

Ground fault current interrupts that use a differential transformer to detect the current imbalance that is indicative of a fault condition have been in use since the 1960's. U.S. Patent No. 3,683,302 (Butler et al.) discloses a sensor for a ground fault interrupter that is operative to detect current imbalances by means of a differential transformer. U.S. Patent No. 3,736,468 (Reeves et al.) discloses a GFCI that uses a differential sense transformer, the secondary of which is amplified to trip a circuit breaker. Other designs that combine a differential sense coil and amplifier combination to trip a circuit breaker upon fault detection include U.S. Patent Nos. 3,852,642 (Engel et al.), 3,859,567 (Allard), 3,936,699 (Adams), 4,216,515 (Van Zeeland), 4,216,516 (Howell), 4,255,773 (Jabbal) and 4,353,103 (Whitlow).

GFCIs, RCDs and AFCIs (collectively "GFCIs") are required by code in many settings. For example, in the United States, GFCI protection is required for the bathroom, garage and outdoor outlets on all new construction. The lifetime of an electrical outlet may be measured in decades but there is no assurance that a GFCI will continue to function properly over that time interval. GFCI outlets that are installed outdoors, or portable GFCI's used with construction equipment, may become encrusted with dirt or corrosion. Electronic components and insulation will age with time and this may cause a degradation in performance. A nearby lightning strike can permanently damage the fault sense electronics in a GFCI. High current demands through the outlet, even in normal use, can cause the contacts on the circuit breaker in the GFCI to weld together, subsequently preventing the circuit breaker from opening even if a fault is correctly sensed. Accordingly, there are GFCI equipped electrical outlets in service today that are not capable of delivering ground fault protection and that are

thereby giving the users of such outlets a false sense of security. Although users should periodically test GFCI units, compliance is typically poor and a manual test can give misleading results or be misinterpreted by the user. As the installed base of GFCI outlets ages, the percentage of defective outlets is likely to increase. These comments apply equally to GFCI or RCD or AFCI devices used in  
5 electrical outlets, distribution panels, portable units, or units that are hard-wired into equipment.

In present day GFCI/AFCI/RCD outlets and load centers that are furnished with manual test buttons, there is no way to ensure that the units are periodically tested. There is also no way to ensure that if they are tested and found to be defective, they will be replaced. A manual test can give  
10 false results or can be misinterpreted by the user. Often manual testing is objectionable because if it removes power from the outlet or load center, even temporarily, it can disrupt appliances that are powered through that outlet or load center. For example, many digital clocks will be reset upon any power outage, even a power outage caused by a momentary manual test. Accordingly, there is a need for a self-testing feature in GFCI devices that is automatic, that is periodic, that is minimally  
15 obtrusive, and that disables the GFCI device in a safe mode if the device cannot afford protection from a ground fault or arcing fault.

U.S. Patent No. 4,051,544 (Vibert) describes a GFCI circuit incorporating an indicator light  
20 that turns on when, and only when, the GFCI circuit breaker opens. This invention was said to be an improvement over the prior art in that prior art devices had indicators that lit when the circuit breaker closed and thus an indicator that was burned out might lead the user to think that an outlet was dead when in fact it was electrically live. While described as a "fail safe GFCI", this invention does not check for the proper functioning of the GFCI.

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The use of an automated test feature incorporated within a GFCI was suggested in U.S. Patent No. 4,031,431 (Gross) wherein the role of the self test is to insure that the polarity on a cordset GFCI is correct for the attachment to the AC source. This invention also purportedly tests the function

of the GFCI. When a control switch on the attached appliance is closed, this implements a synthetic counterbalancing fault to enable the GFCI to function and to allow power to flow to the load. A malfunctioning GFCI is indicated when the appliance continues to operate even when the control switch is in an open position. Since this testing only takes place when the appliance is manually  
5 turned off, the testing mechanism is not automatic. Using this approach does not result in fail safe operation of the GFCI.

U.S. Patent No. 5,477,412 (Neiger et al.) describes a GFCI with built-in intelligence to detect a miswiring condition. The invention incorporates miswiring sense circuitry that automatically triggers  
10 an alarm in the case a miswiring condition is sensed. This invention does not test for the correct functioning of the GFCI.

U.S. Patent No. 4,833,564 (Pardue et al.) describes a test circuit that adjusts the sensitivity of the GFCI to a selected threshold. The testing is not automated but is implemented when a manual  
15 test switch is engaged. The invention purportedly adjusts the magnitude of the test current so as to track changes in the sensitivity setting of the GFCI circuit. This invention does not provide for automatic testing of the GFCI, nor does it provide for fail-safe operation.

U.S. Patent No. 5,459,630 (MacKenzie and Wafer) describes a passive test circuit that  
20 simulates neutral to ground faults and sputtering arc fault events, thus purportedly allowing a GFCI/AFCI to be fully tested. The testing is initiated through a test switch. When a test button is engaged, a bandwidth limited di/dt signal is generated and fed into the arc fault detection electronics, said bandwidth limited di/dt signal purported to simulate a sputtering arcing fault. No means is disclosed for automating these tests. No means is provided for checking for a failure in the circuit  
25 breaker.

U.S. Patents Nos. 5,600,524 and 5,715,125 (Neiger, Gershen and Rosenbaum) describe an intelligent GFCI that periodically tests GFCI fault sensing but relies on the user to check for correct

operation of the fault interruption means (the circuit breaker). This is purportedly done by setting off an audible alarm at periodic intervals, alerting the user to manually check for the proper functioning of the relay portion of the GFCI. The audible alarm then turns off when the user implements a manual test. The problems with this approach are that (1) manual intervention is required to fully check the GFCI, with the user being responsible for recognizing whether the GFCI is correctly operating and for deciding whether to replace a malfunctioning unit; (2) with some failure modes (e.g., a welded hot side relay contact) a manual test will not detect a problem; (3) the audible alarm is obtrusive – for a residential or commercial installation with numerous GFCI's, the need to attend to beeping GFCI's might become a daily (or worse, nightly) burden; and (4) a considerable amount of consumer education will be required in order for the consumer to know that an alarm means "test me" and is not an indication of malfunction. A further problem with these inventions is that the disclosed embodiments use circuit elements that are in parallel with the circuit breaker contacts, so even when the circuit breaker is open, an electrical path from source to load or source to fault will be present. In particular, if one of these parallel components were to fail in a shorted condition, opening the relay would not provide protection against a fault condition and this dangerous operating condition would not be recognized by either the self-testing electronics or by a user implementing a manual test.

A truly fail-safe fault interrupter must incorporate an emergency circuit breaker that removes power from the fault interrupter and load in the case of a malfunction by the fault interrupter. This emergency circuit breaker must be in addition to the normal or primary circuit breaker that is used to interrupt power to the load during normal operation when a ground fault condition is sensed. The reason a fail-safe fault interrupter must have this second breaker is because one common failure mode for the interrupter is when the primary circuit breaker malfunctions, thus preventing the deenergization of the load from the source. This could happen, for example, if the contacts on the primary circuit breaker were to weld together due to the so-called "hot spots" that can occur on oxidized relay contacts. A failure of the primary circuit breaker can also happen if the electronic switch that is used to trigger the circuit breaker fails. Malfunction can also happen due to a stuck or jammed solenoidal plunger, an open circuited or short circuited solenoid, a poor solder joint, a broken



conductor or a variety of other failure sources. While the primary breaker is generally resettable, the emergency secondary breaker be a smaller, less expensive, nonresettable "one-shot". The secondary breaker is only used to open the electrical connection when an interrupter malfunction or fault sensing failure occurs and such an occurrence will generally require that the entire unit be replaced.

A GFCI/AFCI/RCD with the self-testing feature of the present invention can eliminate the need for a manual test button or a manual reset button and may not need a resettable primary circuit breaker, but instead could use a cheaper, smaller, one-shot circuit breaker for both the primary as well as the secondary circuit breakers.

There are a variety of circuit interruption means that comprise the class of one-shot circuit breakers. The most common example is a thermal fuse, whereby two electrical conductors are in electrical contact through a low melting point linkage that opens when the current flow exceeds a certain threshold. U.S. Patent No. 3,629,766 (Gould) describes a circuit breaker wherein a fusible wire link holds spring biased conductors in a closed position. When a predetermined electrical current is passed through the fusible link it causes it to break, effecting the snap action release of the spring arms and breaking the electrical connection. Other examples of circuit interruption means include the one-shot breaker described in U.S. Patent No. 5,394,289 (Yao and Keung) wherein wire fuses connect two sets of two conductors. A current overload is used to break one fuse, whereupon, a cutting element is released to cut through the other fuse. U.S. Patent No. 4,829,390 (Simon) describes a switch that is held in a normally closed position by a flash bulb. A sensor detects a dangerous condition and actuates the flash bulb, causing it to disintegrate and allowing the switch to open. Bimetallic thermal and thermal magnetic circuit breakers are well known in the art and are the basis for many resettable circuit breakers although they can be used for one-shot operation. These work by employing a blade made of two metals having different thermal coefficients of expansion. When the blade is heated, it deforms, breaking a circuit. The magnetic breakers use heating to reduce the magnetic attraction of a magnet, thereby causing a spring loaded contact to release and

open a circuit. Other designs for circuit breakers include piezoelectric actuators as in U.S. Patent No. 4,473,859 (Stone et al.) and shape memory alloy actuators as in U.S. Patent No. 3,403,238 (Buehler and Goldstein).

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## SUMMARY OF THE INVENTION

The present invention is of a self-testing fault interrupt method and apparatus comprising: a) detecting an electrically unsafe operating condition via a fault sensing component; b) preventing power delivery upon the detection of an electrically unsafe operating condition via a primary electrical current interrupting component; c) employing a fault sense testing component that periodically and automatically disables the primary electrical interrupting component, applies a simulated fault, verifies that the fault sensing component correctly detects this simulated fault, removes the simulated fault, and reenables the primary electrical current interrupting component if the fault sensing component correctly detected the simulated fault; d) employing a circuit breaker testing component that, when the fault sensing component detects an electrically unsafe operating condition, automatically checks that the primary electrical current interrupting component has satisfactorily interrupted power delivery; and e) employing a secondary electrical current interrupting component that permanently removes power from the self-testing fault interrupt apparatus if the fault sense testing component does not correctly detect a simulated fault or if the circuit breaker testing component determines that the primary electrical current interrupting component has not satisfactorily interrupted power delivery. The primary electrical current interrupting component preferably comprises a solenoidal relay, a bimetallic thermal circuit breaker, thermal magnetic circuit breaker, piezoelectric acutuated circuit breaker, shape memory alloy circuit breaker, or circuit breaker employing a fusible link. The secondary current interrupting component can employ a one shot circuit breaker and can interrupt both or only one of two current carrying conductors. The secondary current interrupting component can employ solenoidal relays, bimetallic thermal circuit breakers, thermal magnetic circuit breakers, piezoelectric actuated circuit breakers, shape memory alloy actuated circuit breakers or circuit breakers employing a fusible link. The secondary current interrupting component can employ conducting blades that are forced apart by an insulating wedge to interrupt power flow, with the conducting blades connecting the

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insulating wedge to a spring held in compression by a low wattage resistor, and releasing the spring when a high electrical current is passed through the low wattage resistor. Outlets with or without manual test and reset switches may be employed in conjunction with the invention.

5           Prior art approaches to self-testing in ground fault current interrupts are complicated; are not completely automated; do not test for a malfunctioning circuit breaker; and do not fail safe. In particular, for fail safe operation, a failure of any one individual component in the system may not result in a device that will be unsafe if a ground fault occurs. Accordingly, the present invention has the following objects and advantages:

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a.       It automatically and periodically checks for the correct operation of the ground fault sensing circuitry;

b.       The self-testing electronics are completely independent of the GFCI/AFCI/RCD electronics;

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c.       The self-testing electronics can be added as a retrofit to some existing GFCI/AFCI/RCD circuits with minimal or no redesign;

d.       The self-testing works independent of any manual test button that may optionally be present  
20       and the user is not relied upon to be an element of the testing routine or to be responsible for identifying a malfunctioning GFCI/AFCI/RCD;

e.       The automatic testing does not disrupt the functioning of any appliances that may be powered through the GFCI/AFCI/RCD;

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f.       The invention requires only a small number of relatively low cost components to implement;

g.       Using the present invention, a person cannot be injured by a ground fault unless both the

GFCI/AFCI/RCD portion and the self test circuit are damaged. If either one is functional then protection is afforded;

- h. The present invention will protect against injury even in the case of a failure of the  
5 GFCI/AFCI/RCD primary circuit breaker;
- i. The use of the present invention reduces and may eliminate the need for a manual test  
button and manual reset button and the attendant costly, and bulky mechanical components  
associated with having mechanical interlocks and latches for ensuring safe resetting after a  
10 manual test; and
- j. For a cordset application, the present invention allows the use of a normally closed relay for  
the primary electrical current interrupting component.

15 It is a general object of the present invention to provide an automatic self-testing feature for  
ground fault current interrupt circuits and arc fault current interrupt circuits that removes power from  
the GFCI/AFCI/RCD and the load when a circuit malfunction in the GFCI/AFCI/RCD is detected.

It is another object of the present invention to implement this self-testing automatically without  
20 human intervention.

It is another object of the present invention to implement the self-testing circuit with a minimal  
number of electronic components, thereby containing cost, complexity and avoiding the introduction  
of numerous additional failure modes.

25 It is another object of the present invention to provide a testing circuit that is independent of  
the electronics in the GFCI/AFCI/RCD portion of the circuit and that can be implemented as a retrofit  
to existing GFCI/AFCI/RCD circuits.

It is a further object of the present invention to provide protection against injury in case of failure of the GFCI/AFCI/RCD circuit breaker, and in particular, if a solenoid for the circuit breaker is shorted or stuck or if the circuit breaker contacts fail to open.

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It is a further object of the present invention to eliminate the need for a manual test and manual reset means for the GFCI/AFCI/RCD, thereby eliminating some of the expense and mechanical complexity associated with prior art devices.

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It is a further object of the present invention to provide a safety system such that the failure of any single component in the entire system will not compromise the safety of the user.

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None of the prior art embodiments, either alone or in combination, anticipates the present invention. Other objects, advantages and novel features, and further scope of applicability of the present invention will be set forth in part in the detailed description to follow, taken in conjunction with the accompanying drawings, and in part will become apparent to those skilled in the art upon examination of the following, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

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#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 - Block diagram of prior art GFCI circuit.

FIG. 2 - Block diagram of GFCI with attached test circuit.

FIG. 3 - Flowchart for self-testing GFCI

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FIG. 4 - Specific embodiment of a commercially available GFCI (Prior Art).

FIG. 5 - First specific embodiment of automatic, self-testing GFCI.

FIG. 6 - Second specific embodiment of automatic self-testing GFCI.

FIG. 7 - Detail of one-shot circuit breaker control.

FIG. 8 - Details of two one-shot breaker controls with indicators.

FIG. 9 - Mechanical layout of a portion of a prior art GFCI device.

FIG. 10 - First specific embodiment of a one-shot breaker.

FIG. 11 - Mechanical layout of GFCI with self-tester added as a retrofit.

5 FIG. 12 - One-shot breaker using shape memory alloy actuator.

FIG. 13 - Side view of one-shot breaker.

FIG. 14 - Alternate view of one-shot breaker.

FIG. 15 - Permanent outlet with removable GFCI/AFCI

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# LIST OF REFERENCE NUMERALS

- 22 - AC1 source conductor
- 24 - AC2 source conductor
- 26 - Current sense transformer
- 15 28 - Secondary winding of current sense transformer
- 30 - Detection electronics
- 32 - Hot side circuit breaker contact
- 33 - Neutral side circuit breaker contact
- 34 - Load
- 20 36 - Solenoid
- 38 - Load side electrical leakage path
- 39 - Earth ground
- 40 - Electrical leakage path from load to ground
- 42 - Primary relay trigger SCR
- 25 44 - Power connection of the amplifier to AC1
- 46 - Power connection of the amplifier to AC2
- 48 - Current limiting resistor connecting amplifier to SCR gate
- 50 - Manual test button
- 52 - Fault test resistor
- 30 54 - SCR cathode
- 56 - Self test circuit control block
- 57 - Conventional GFCI
- 58 - AC1' source conductor
- 60 - AC2' source conductor
- 35 62 - AC1 to test circuit
- 64 - AC2 to test circuit
- 66 - Hot side secondary circuit breaker
- 67 - Neutral side secondary circuit breaker
- 68 - Trigger for secondary circuit breaker
- 40 70 - Fault sense signal
- 72 - SCR disable connection
- 74 - SCR gate
- 75 - Connection to AC1 conductor on load side of current sense transformer
- 76 - Fault resistor for automatic test
- 45 78 - Control for self-test switch for fault test
- 80 - Fault detection trigger output from detection electronics

- 82 - Electronic switch for fault test
- 84 - Decision block "has fault occurred?"
- 86 - Delay block to allow circuit breaker time to open
- 88 - Decision block "Is fault being sensed?"
- 5 90 - Block to activate secondary circuit breaker
- 92 - Decision block "Time for self-test?"
- 94 - Block to disable primary circuit breaker SCR gate
- 96 - Block to apply a test fault
- 98 - Decision block "Is fault sensed?"
- 10 100 - Block to remove test fault
- 102 - Block to enable primary circuit breaker
- 104 - Block to reinitialize timer
- 106 - Metal oxide varistor
- 108 - Full wave bridge
- 15 110 - Power sourcing resistor
- 112 - Node for positive DC power
- 114 - Filter capacitor
- 116 - Reference node for DC power supply
- 118 - Amplifier/filter
- 20 120 - Detection electronics block (detail)
- 122 - Coupling capacitors
- 124 - Filter capacitor for SCR gate
- 126 - SCR disable switch
- 128 - Test circuit
- 25 130 - Microcontroller
- 132 - Dropping resistor
- 134 - Rectifier diode
- 136 - Charge capacitor
- 138 - Dropping resistor
- 30 140 - Power supply capacitor
- 142 - Zener diode
- 144 - Resistor to AC line
- 146 - Inhibit line
- 148 - Optocoupled transistor
- 35 150 - Optocoupled transistor
- 152 - Test button
- 153 - Optocoupled Triac
- 154 - One shot control line
- 155 - Test fault resistor
- 40 156 - Resistor
- 158 - Pull up resistor
- 160 - Disable transistor
- 162 - Base resistor
- 164 - Resistor
- 45 166 - Diode
- 168 - SCR
- 170 - Cathode to gate resistor
- 172 - Fault sense input
- 173 - One shot circuit breaker
- 50 174 - Breaker actuator
- 175 - Circuit breaker contact
- 176 - Circuit breaker contact
- 177 - Resistor
- 178 - Neon lamp
- 55 179 - Resistor
- 180 - Source terminal block

- 182 - Screw
- 184 - Threaded hole
- 186 - Electrical insulating structure
- 188 - Rivet
- 5 190 - Conducting blade
- 192 - Printed circuit board with GFCI electronics
- 194 - Torroid
- 196 - Secondary windings of sense transformer
- 198 - Contact points
- 10 200 - Rivet holding AC source terminal to PC board
- 202 - Printed circuit board
- 204 - Rivet holding blade to printed circuit board
- 206 - Copper pad
- 208 - Conductors
- 15 210 - Insulating wedge
- 212 - Slotted track
- 214 - Springs
- 216 - Carbon composition resistor
- 218 - Hole in printed circuit board
- 20 220 - Hole in insulating wedge
- 222 - Male connectors from self-test printed circuit board
- 224 - Female connectors on GFCI printed circuit board
- 226 - Shape memory alloy wire
- 228 - Post
- 25 230 - Stationary structure
- 232 - Large pin
- 234 - Compression spring
- 236 - Slide attached to insulating wedge
- 238 - Back plate connected to insulating wedge
- 30 240 - Small pin
- 242 - Extension of stationary structure into wedge
- 244 - Permanent outer shell
- 246 - GFCI/AFCI component
- 248 - Test button
- 35 250 - Reset button

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 gives a block diagram that functionally describes the majority of present day GFCI circuits. This is the prior art circuit that is the basis for almost any GFCI found in the home or in commercial and industrial construction. This circuit, or a variant thereof, is used for fault detection/interruption in load distribution centers, in wall outlets, in extension cords, and on dedicated electrical appliance cord sets. The incoming conductors from the source are the AC1 22 and AC2 24 conductors. In the U.S., one of these conductors (for this discussion the AC2 conductor 24) is generally required by code to be grounded at a distribution panel and is known as the "neutral" conductor. In such a system, the ungrounded current carrying conductor is often called the "hot"



conductor. Conductors 22 and 24 pass through a differential current sense transformer 26 and thereby act as the primary for that transformer. The secondary 28 of current sense transformer 26 connects to the detection electronics 30, which may filter and/or amplify and/or otherwise process the voltage from the secondary windings 28 of the current sense transformer 26. The detection electronics draw power from connections 44 and 46. In normal operation, electrical current is delivered to the load 34 through circuit breaker contacts 32 and 33. In some applications, such as in a load distribution panel, there is a single circuit breaker contact 32 for interrupting electrical current on the ungrounded conductor and there is no circuit breaker contact 33 (equivalently, circuit breaker contact 33 is always in a closed position). For a system with two circuit breaker contacts 32 and 33, circuit breaker contacts 32 and 33 are closed during normal operating conditions but are driven to be in an open condition by solenoid 36 if a ground fault condition is detected. For most present day fault interrupters, circuit breaker contacts 32,33 are part of either a circuit breaker or a normally open (Form A) relay. The reason for using these two configurations is that once circuit breaker contacts 32,33 are placed in an open condition, they will maintain that open condition even in the absence of power. By contrast, a normally closed (Form B) relay, while preferable to a normally open relay because of its greater power handling capability, is seldom used for circuit breaker contacts 32,33 because if it fails, it is likely to do so in an unsafe (contacts closed) condition. As will be seen, with the present invention, a normally closed relay can be used for circuit breaker contacts 32,33 without compromising safety.

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In normal operation in the absence of a ground fault, the same amount of electrical current flows in the AC1 and AC2 conductors 22 and 24, but in opposite directions. The net flux in the differential current sense transformer 26 is near zero and the voltage that is generated in the transformer secondary 28 is zero. When a load side electrical leakage path 38, occurs from the AC1 conductor to ground or an electrical leakage path 40 occurs from within the load 34 to ground 39, then there is a current imbalance between conductors 22 and 24. This results in a net magnetic flux that is induced in the differential current sense transformer 26. This results in a nonzero voltage being generated in the secondary 28. The detection electronics 30 then takes in this voltage signal and

processes it to determine whether a current imbalance (a fault) of sufficient magnitude and/or duration has occurred. If the detection electronics 30 determines that the fault is of sufficient magnitude and/or duration, then it triggers an SCR 42 into conduction which causes current to flow through the solenoid 36, thereby opening the circuit breaker contacts 32,33. In FIG. 1, the SCR cathode 54 will generally connect, within the detection electronics 30, to AC2 24, directly or through one or more series resistors and/or diodes. A current limiting resistor 48 may be used to connect the detection electronics 30 to the gate 74 of the SCR 42. In some implementations, there will be no current limiting resistor 48 but an amplifier output within the detection electronics 30 will connect directly to the gate 74 of SCR 42 (equivalently, current limiting resistor 48 is a short). In some implementations, the SCR 42 will be replaced by an alternative electric switching element such as a triac or a transistor or an optically isolated switching element.

Test button 50 allows a manual test of the proper operation of the fault sensing/interrupting circuitry. When test button 50 is engaged, it implements an electrical leakage path that goes around the differential current sense transformer 26. The amount of electrical leakage is determined by the resistance value of the fault test resistor 52. This deliberately applied electrical leakage causes a current imbalance that is sensed by the detection electronics 30 and then triggers the primary relay SCR 42 which energizes the solenoid 36, thereby causing the circuit breaker contacts 32,33 to be opened. A user can thus manually test the GFCI by engaging the test button 50 and listening for the relay contacts 32,33 to open and/or observing a visual indicator (for example, in many implementations, the reset button will pop up). The visual indicator can be misleading since with some failure modes, e.g., a single welded hot side contact, the reset button may still pop up during a manual test, leading a user to incorrectly believe that the GFCI is offering fault protection. In many implementations, the relay has a reset mechanism that can be manually engaged to reclose the relay after it has opened. In many implementations, the GFCI will have a second current transformer (not shown) that will be used for detecting a neutral to ground fault. Generally, if the GFCI has a manual test means, this test means will be directed at detecting a hot to ground fault and will not test for the correct function of the neutral to ground fault detection.

While the above discussion has centered around a ground fault detection circuit, an arc fault simulation circuit can be built into the detection electronics **30** and be triggered by the manual test button **50** to implement a manual arc fault test.

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FIG. 2 depicts a block diagram of a conventional GFCI (dotted box **57**) with the self-test circuit **56** of the present invention added. One of the important features of the present invention is that it can be added as a retrofit to an existing GFCI design. This is seen by the fact that the self-test circuit **56** connects to the existing GFCI circuit in four places (at the two sides of resistor **48**, to the SCR cathode **54**, and through conductor **75** to the AC1 conductor on the load side of the current sense transformer **26**), without otherwise affecting its operation. Part of the test circuitry entails the addition of a secondary circuit breaker **66** and **67** that serves to interrupt power by breaking the connection between respectively, conductors **58** and **22** and between conductors **60** and **24**. In some embodiments, particularly for a GFCI/AFCI in a load center, it may not be desirable to interrupt current flow on the neutral side, in which case circuit breaker **67** would be replaced by a direct electrical connection between the AC2' source conductor **60** and the AC2 source conductor **24**. The secondary circuit breaker **66** (and optionally **67**) is nominally in a closed state unless triggered to open by the self-test circuit **56** via a trigger signal **68**. The self-test circuit **56** receives its power from the AC source through conductors **62** and **64**.

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During normal operation when the self-test circuit **56** is not active, the connections to lines **70** and **72** are in a high impedance condition and have no effect on the normal functioning of the GFCI. At periodic or random time intervals, an automatic test is implemented by the self-test circuit **56**. During the automatic test, first the self-test circuit **56** automatically disables the primary relay SCR **42** by tying the SCR gate **74** to a potential at or near the potential at SCR cathode **54**. This is done via the SCR disable connection **72**. While the SCR **42** is disabled, an artificial fault is implemented by engaging switch **82**, which applies a test resistance **76** to AC2' **60** around the current sense transformer **26**. If the GFCI is correctly sensing a fault condition, this should result in a high going

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voltage triggering signal on conductor 80. This would normally result in the firing of SCR 42 but does not do so during a self-test because line 72 is disabling the SCR gate 74. If the self-test circuit senses a high going voltage via conductor 70 that is of sufficient magnitude and duration that it would normally trigger the primary relay trigger SCR 42, this means that the GFCI correctly sensed a fault condition and everything in the GFCI up to this trigger output 80 is functioning correctly. The self-test has been passed, test switch 82 is put back into an open condition, thereby removing the test fault, and line 72 is then placed back into a high impedance condition, thereby enabling the normal operation of the GFCI.

10 If, on the other hand, while a test fault 76 is engaged through switch 82 during a self-test, the detection electronics 30 does not generate a trigger voltage at line 70 of sufficient magnitude and duration, this indicates that there is a malfunction within the sensing portion of the GFCI. In this event the self-test circuit 56 opens the secondary circuit breaker via control line 68, thereby removing power from the GFCI 57 and the load 34 and rendering the entire system safe.

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Accordingly, the self-test circuit 56 periodically and automatically checks for the proper functioning of the fault sense portion of the GFCI. This leaves the circuit interruption component of the GFCI, including the primary relay trigger SCR 42, the solenoid 36, the circuit breaker contacts 32,33 and any connections between them, untested. The circuit interruption portion of the GFCI is tested at any time that the GFCI trigger output 80 becomes active when a self test is not being implemented. When a self test is not being implemented, then line 72 is in a high impedance state, enabling the SCR 42. Any fault that is sensed, including a legitimate fault to ground 38 or a fault 40 from load to ground, or a test fault 52 that is implemented via the manual test button 50, should result in a signal at the output 80 of the detection electronics 30 that will trigger the SCR 42, energizing the solenoid 36 and thus causing the circuit breaker contacts 32,33 to open.

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Accordingly, at any time that a self-test is not being carried out and the test circuit detects a trigger signal through conductor 70, it signifies an event that should cause the circuit breaker contacts

32,33 to open, thereby removing the fault condition and causing the trigger signal 80 to become inactive after sufficient time has elapsed to allow the circuit breaker contacts 32,33 to fully open (which would remove the leakage path so that no fault would be sensed). If, after a time interval that is long enough so that the circuit breaker 32,33 should have opened in response to a fault, the trigger  
5 signal 80 is still in an active condition, this indicates that the fault condition has not been removed. This can happen for a variety of reasons, including, but not limited to, one or more welded contacts in the circuit breaker, a broken conductor, a malfunctioning SCR 42, or because the fault occurred on the GFCI side of circuit breaker contacts 32,33. For whatever reason, if a fault of significant magnitude has been sensed but the fault condition has not been removed within a certain interval,  
10 then this is indicative of a failure of the GFCI or partial failure of the test circuit and the self-test circuit 56 triggers the secondary circuit breaker contacts 66,67 to go into an open state by means of trigger 68.

The above discussion has not addressed testing for a neutral to ground fault condition. In  
15 many GFCI's, a second current transformer will be added, generally adjacent to the first current sense transformer, to sense a neutral to ground fault condition. Neutral to ground faults are often detected by introducing a signal onto the neutral conductor which is coupled back to the sense coil through the loop completed by the neutral to ground fault. This feedback then serves to cause an amplifier within the GFCI to recognize a fault condition. This neutral to ground protection is important because it  
20 protects against the occurrence of a grounded neutral on the load side of the GFCI circuit breaker and helps ensure that a GFCI outlet is correctly wired. However, for a correctly wired GFCI, a neutral to ground fault is seldom a shock hazard since the potential difference between neutral and ground is generally less than a volt. Accordingly, most commercial GFCI's do not include a manual test button to test for the response to a neutral to ground fault. It would be obvious to one skilled in the art that  
25 the previous discussion can be extended to the inclusion of neutral to ground protection within the GFCI and the inclusion of an additional electronic test switch to implement a test for neutral to ground fault.

The above discussion has not addressed the self-testing of an arc fault detection/interruption capability. AFCI's will generally be combined with GFCI's and will share the same circuit interruption means (circuit breaker contacts 32,33, solenoid 36, SCR 42, etc.) and possibly some of the same detection electronics. It would be obvious to one skilled in the art that the previous discussion can be extended to the inclusion of arc fault self-testing.

FIG. 3 depicts a flow chart for the sequence of tasks that should be carried out by the self-test circuit 56 of FIG. 2. In the main loop, the tester looks for whether a fault has been detected 84. If true, this indicates either a ground fault has occurred or that a manual test has been initiated. After a delay 86 sufficient to allow the primary circuit breaker to open in response to a fault, the tester again looks for whether a fault is being detected 88. If the answer is again yes, then clearly, the primary interruption means of the GFCI is not properly functioning and the tester proceeds to activate the secondary circuit breaker 90, thereby removing power from the GFCI, the load and any leakage paths to ground.

In the main loop, as the tester checks for whether a fault has been detected 84, if no fault has been detected then it checks to see if enough time has elapsed to initiate a self-test 92. In practice, this time delay governs how often the fault detect electronics are checked and this time interval may be set to any arbitrary amount from seconds to days. If sufficient time has elapsed, then a self-test is performed by first disabling the primary circuit breaker 94 and then applying a test fault 96. If a fault is sensed 98 this indicates that the fault sense electronics are functioning correctly, so the test fault is removed, 100, the primary circuit breaker is enabled 102, the timer is reinitialized 104, and the cycle repeats. If, on the other hand, no fault is sensed 98 after a test fault is applied 96, this indicates that the fault sense electronics are defective and the secondary circuit breaker is activated 90 to force the removal of power from the system and placing the system in a safe condition.

The two main branches of the flow chart in FIG. 3 embody the essence of this invention. The ability to sense a fault is continually checked in the main loop so that at any time there is confidence

that this portion of the circuit works. Then, when a fault is sensed due to external factors (either a true fault or a manual test) the correct functioning of the relay is checked by verifying that after a brief time interval the fault condition is removed. If the fault condition is not removed, this is indicative of a defective GFCI and power is permanently removed.

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FIG. 4 depicts a specific embodiment of a commercially available GFCI circuit. As in previous figures, the source conductors AC1 and AC2 (22 and 24) pass through the current sense transformer 26, thereby forming the primary side of the transformer. A metal oxide varistor 106 serves to act as a low impedance shunt to high voltage spikes, thereby affording protection to the electronics in the GFCI. Full wave bridge 108 serves to full wave rectify the incoming alternating current. Some of the voltage from the line is dropped across the power sourcing resistor 110, thereby ensuring that the DC voltage at node 112 is at a relatively low 12 to 16 volts. Filter capacitor 114 connects between the positive DC node 112 and the reference node for the DC power supply 116. The amplifier/filter 118 is generally implemented on a single integrated circuit. The dotted box 120 represents the detection electronics block 30 of FIG. 1 and FIG. 2.

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In FIG. 4, capacitors 122 serve to couple the signal from the secondary 28 of the differential transformer 26 to the amplifier/filter 118. Capacitor 124 serves to filter out high frequency noise, thereby preventing an accidental firing of the primary relay trigger SCR 42. The trigger output 80 connects to the gate 74 of SCR 42 through a current limiting resistor 48. In many commercial GFCI's an SCR disable switch 126 is present. This switch automatically engages when the circuit breaker contacts 32,33 open, thereby shorting the gate of the primary trigger SCR 42. This ensures that the current is removed from the solenoid 36 after the relay opens, protecting the solenoid 36 from being continuously energized and preventing nuisance trips when the GFCI is manually reset. Often the mechanical breaker is constructed in such a way as to only allow the breaker contacts to close with the reset actuator released (prevents breaker from being held closed while a fault is present).

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FIG. 5 depicts a first preferred embodiment of the automatic, self-testing GFCI circuit. The

dotted box **128** corresponds to the self-test circuit **56** from FIG. 2. The microcontroller **130** forms the heart of the self-test circuit and implements all timing and control features. The microcontroller **130** can be a single integrated circuit and could be implemented as a programmed, commercially available integrated circuit or as a custom, application specific integrated circuit (ASIC). The microcontroller receives its power at terminals Vdd and Vss. Vdd is approximately 5 volts relative to Vss (which is tied to AC2) and is generated from the incoming AC by using a dropping resistor **132** into a rectifying diode **134** to a charge capacitor **136**. The voltage across the charge capacitor **136** is then filtered and regulated by the dropping resistor **138**, the power supply capacitor **140** and the zener diode **142**.

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The self-test circuit **128** is added as a separate, independent item and is designed to have minimal impact on the function of the original GFCI. In particular, the manual test button **50** and manual reset mechanisms can be unchanged. The microcontroller **130** implements timing from the AC line to which it is connected through a resistor **144**. AC line voltage cycles are generally very stable in frequency. By counting the zero crossings of this line, the microcontroller can implement timing functions.

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The microcontroller implements a test of the fault sense electronics by carrying out the steps outlined in the flowchart of FIG. 3. First, it disables the primary relay trigger SCR **42** by placing inhibit line A **146** in a high state and inhibit line B **156** in a low state. This serves to trigger an optocoupled transistor **148** that disables the SCR **42**. Next, the microcontroller implements a test fault by placing the test button output **152** at a Vss potential. This serves to energize the optocoupled triac **153** which then implements a test fault of a magnitude governed by resistor **155**. This test fault results in an imbalance of currents through current sense transformer **26** since the test path goes through the transformer **26** via the AC1 conductor **22** but returns to AC2 **24** without going through the transformer **26**. Finally, the microcontroller **130** checks the status at optocoupled transistor **150** to see if a fault has been recognized. At any time that the GFCI is determined to be damaged or malfunctioning, the microcontroller energizes the one shot line **154** to permanently remove power from the entire system.

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When the test is over, the microcontroller places inhibit line A **146** in a low state and inhibit line B **156** in a high state. The purpose of two inhibit lines to control optocoupled transistor **148** is so in case of failure of the overall test circuit **128**, the optocoupled transistor **148** will be unlikely to be placed in a mode where it disables the SCR **42**. Should transistor **148** fail in a disabling mode, the test circuit will  
5 detect this as a failure of the main breaker in an actual fault condition, and will fire the one-shot, permanently removing power from the GFCI and the load.

In the embodiment in FIG. 5 the GFCI portion of the system is completely independent of the test circuit **128**. Each subsystem has its own independent power supply. The only interface between  
10 the two circuits is via optical coupling. Accordingly, a failure in one circuit does not electrically alter the other circuit with the exception of optocoupled transistor **148** which is equipped with two control lines in order to make it unlikely to be a failure mode. Should transistor **148** fail in a disabling mode, the test circuit will detect this as a failure of the main breaker in an actual fault condition, and will fire the one-shot thus causing the system to fail safe.

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FIG. 6 depicts a second preferred embodiment of the self-testing GFCI. The main distinction between FIG. 5 and FIG. 6 is that the embodiment in FIG. 6 does not require relatively expensive optocoupled components. Instead, in the embodiment in FIG. 6, the reference potential for the test  
20 circuit **128** is tied to the reference node **116** for the GFCI. This enables all signals from the GFCI and test circuit to be at the same voltage levels.

The power supply in FIG. 6 functions identically to that of FIG. 5. During the testing sequence, first the microcontroller disables the relay trigger SCR **42** by tying the base high and the emitter low of transistor **160**. This serves to short out the gate **74** of SCR **42**. Next, a test fault is  
25 implemented using the test output **152**. This implements a fault by triggering SCR **168**. Finally, the fault sense is monitored at the sense input **172** on the microcontroller **130**. As before, if a malfunction of the GFCI is sensed, the one shot **154** is triggered.

The embodiment in FIG. 6 can be built using a PIC 12C508 microcontroller that is commercially manufactured by the Microchip company. One of the advantages to this microcontroller is that it has an internal watchdog timer that is independent of the oscillator used to carry out the microcontroller timing. The watchdog timer will periodically generate an interrupt, forcing the system  
5 into an initialization sequence unless it is disabled periodically within the microcontroller software. Accordingly, it provides a layer of safety in case the microcontroller is "glitched" due to electrical noise. Due to the limited burden on the microcontroller, the choice of the microcontroller would likely be dictated by cost. Alternatively, the logic could be implemented by one or more commercially available integrated circuits or by a custom-built application specific integrated circuit. Because the  
10 embodiments in FIG. 5 and FIG. 6 incorporate a means to remove power from the load even in the event of a failure of the circuit breaker opening mechanism associated with circuit breaker contacts 32,33, circuit breaker contacts 32,33 can be part of a normally closed (Form B) relay. A normally closed relay is preferable to a normally open relay because when a normally open relay is controlled to be in the closed position, it may close into a load condition that could draw excessive electrical  
15 currents. Such high current values can be damaging to the relay contacts. Furthermore, in a normal operating condition, a normally closed relay requires negligible power to engage the relay contacts. In contrast, a normally open relay generally requires significant power to engage the relay contacts.

While both FIG. 5 and FIG. 6 depict circuits having a manual test button 50, and might  
20 represent systems having a (not depicted) manual reset button, the addition of self-testing to the fault detection circuit makes the manual test button 50 unnecessary. For an implementation that is incorporated into an extension cord or an appliance electrical cord, the reset function could be accomplished by simply toggling the applied power or by unplugging the unit.

25 FIG. 7 depicts a preferred embodiment for the one-shot circuit breaker 66,67. The one-shot control line 154 is used to trigger an SCR 173 that allows a current flow through breaker actuator 174. The breaker actuator 174 is depicted as a resistor and in some embodiments may, in fact, be a resistor whose function is to disintegrate due to high power when the SCR 173 is fired, thereby

releasing a mechanism that opens the one-shot contacts **175** and **176**. The breaker actuator **174** may also be a shape memory alloy wire, which when heated due to current flow within the wire, changes its shape, thereby releasing a mechanism that opens the one shot contacts **175** and **176**. It will be obvious to one skilled in the art that the breaker actuator could also be a relay coil, a bimetallic strip, a piezoelectric actuator, or another type of electrical element that causes a mechanical response when energized.

FIG. 8a is identical to FIG. 7 except that electronic circuitry has been added to indicate when the one-shot breaker is in an open condition. This could be used to indicate to a user that a malfunction has occurred. A neon indicator **178** serves to give a visual indication when the breaker contact **175** is open. The current to neon **178** is limited by a limiting resistor **177**. A second resistor **179** which connects from AC1 to AC2', serves to give a path for current flow through the neon **178** when both contacts **175** and **176** are open. Resistors **177** and **179** should be chosen to be relatively large in resistance value so as to limit any fault currents. In a 115 VAC electrical system, one possible set of values is to choose a value of 47 kilohm for resistor **177** and a value of 68 kilohm for resistor **179**.

FIG. 8b depicts a one-shot breaker with a different type of indicator. In this system, when breaker contact **175** is closed, the NPN transistor **181** is in an off condition because the base of transistor **181** has a voltage that is lower than the emitter. As such, no current flows through the neon **178**. When the breaker contact **175** opens, the base voltage on the transistor **181** increases to turn on transistor **181** during the half cycles when AC2' is positive with respect to AC1'. This causes an appreciable current to flow through the neon **178**, causing it to turn on during these half cycles. The emitter resistor **185** serves to limit the current through the neon **178** and ensures that the transistor **181** is turned off when contact breaker **175** is in a closed state. Diode **183** protects the transistor **181** from being damaged due to reverse currents on alternating half cycles.

FIG. 9 depicts the mechanical layout of a prior art GFCI. This layout is functionally equivalent

to many commercially available GFCI devices. The source terminal blocks **180** are locations to which current carrying conductors from the AC source are attached. The attachments are generally made by using a threaded screw **182** to attach wires from the AC source into a hole **184**. An electrical insulating structure **186** is used to mechanically secure the source terminal blocks **180** and to keep them isolated from one another. One or more rivets **188** may be optionally used to secure the source terminal blocks to the electrical insulating structure **188**. Two conducting blades **190** that are electrically connected respectively to each of the two source terminal blocks **180**, extend down through a printed circuit board **192**. These blades **190** make an electrical connection to the printed circuit board **192**, thereby furnishing power to the electronics therein. The electrical connection can be via soldering or can be a press fit. The blades **190** also pass through a torroid **194**, thus acting as the primary side of a transformer wound on the torroid **194**. The secondary windings **196** of this transformer connect to the GFCI electronics. The blades **190** that are electrically connected to the AC source, go through the printed circuit board **192** to connect to one side of the primary circuit breaker (not shown). The other side of the primary circuit breaker then connects to output, or load, terminals (not shown). In FIG. 9, the other electronic components shown on the printed circuit board **192** are for illustration only and may not correspond to the actual electronics on a GFCI device.

FIG. 10 depicts a preferred self-testing retrofit circuit embodiment of the invention. This assembly would replace the electrical insulating structure **186** and source terminals **180** of the previous FIG. 9. In FIG. 10, the source terminals **180** perform the same function as previously, serving as a mounting point for the incoming AC conductors. In normal operation, when the GFCI circuit is functioning normally, the source terminals **180** connect electrically to the blades **190** through contact points **198**. Rivets **200** serve to hold the source terminals **180** secure to a printed circuit board **202**. Rivets **204** serve to hold the blades **190** secure to the printed circuit board **202** and to ensure that the blades **190** do not make electrical contact with one another. Rivets **204** also assist in making a solid electrical connection between the blades **190** and copper pads **206** on the printed circuit board **202**. Contact points **198** are normally held against copper pads **206** by the spring pressure of conductors **208**, which act like leaf springs.

A spring loaded insulating wedge **210** is held in place and guided by a slotted track **212** in the printed circuit board **202**. When the self test electronics detect a dangerous operating condition, the wedge **210** is forced between the contacts **198** and the copper pads **206**, serving to break the electrical connection. The wedge **210** can move in the direction of the slotted track **212**. A protrusion in the bottom of the wedge **210** serves to prevent the wedge from twisting or slipping out of the slotted track **212**. The insulating wedge **210** may be made out of glass, teflon, Delrin or some other electrically insulating material. Two springs **214** are positioned between the back of the insulating wedge **210** and the printed circuit board **202**. These springs **214** serve to apply a bias force on the wedge **210** in a direction so that they would cause the contact points **198** to open. The wedge **210** is prevented from moving in reaction to these springs **214** by a quarter watt carbon composition resistor **216** which is mechanically connected to the printed circuit board **202** through a hole **218** and is mechanically connected to the wedge **210** through a hole **220**. When the self test detects a dangerous operating condition, a high current is passed through the resistor **216**, causing it to disintegrate, and thereby allowing the springs **214** to force the wedge between the contact points **198** and the copper pads **206**, breaking the electrical connection and removing power from the blades **190**, and consequently, removing power from the GFCI electronics and the load.

FIG. 11 depicts one way in which the invention can be implemented as a retrofit with an existing GFCI circuit. In FIG. 11, the printed circuit board **202** contains the electronic components necessary to implement the self-test. The electronic components that are depicted are for illustration only and do not necessarily correspond to the actual components that would be used. Four connections must be made from the self-tester electronics on the printed circuit board **202** to the printed circuit board with GFCI electronics **192**. These connections may be made via male connectors **222** on the self-test printed circuit board **202** to female connectors **224** on the GFCI printed circuit board **192**. Two of these connections go to either side of the current limiting resistor connecting amplifier to SCR gate. A third connection attaches to the AC1 conductor on the load side of the solenoid. A fourth connection attaches to the cathode of the primary relay trigger SCR.

By comparing FIGS. 9 and 11, it is seen that a conventional GFCI device can be easily converted to a self-testing GFCI device by simply replacing the electrical insulating structure **186** with a self-test PC board **202**.

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FIG. 12 depicts a self-testing retrofit assembly of the invention analogous to the structure depicted in FIG. 10. As in the earlier figure, source terminal blocks **180** are connected to conducting blades **190** via conductors **208** which connect to contact points **198** which in turn make electrical contacts with copper pads **206**. The conducting blades **190** connect to the GFCI electronics (not shown) and to the main circuit breaker (not shown). Rivets **200** and **204** serve to hold the conducting elements secure to the printed circuit board **202**. When the one shot circuit breaker is activated, an insulating wedge **210** is forced by springs **214** to separate the contact points **198** from the copper pads **206**, thereby breaking the electrical connection between the source terminals and the conducting blades **190**. When the one-shot circuit breaker is activated, the insulating wedge **210** is allowed to move forward in a slot **212** in the printed circuit board **202**. Prior to the activation of the one-shot circuit breaker, the springs **214** are in compression. Prior to the activation of the one-shot circuit breaker, the insulating wedge is prevented from moving by a large pin **232** which passes through the insulating wedge into a stationary structure **230**.

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FIG. 13 presents a side view of the insulating wedge **210**. The insulating wedge **210** is connected to a slide **236** that lies in a slot on the printed circuit board (not shown). Connecting to the slide **236** is a back plate **238** that goes on the back of the printed circuit board and gives stability. Stationary structure **230** is affixed to the printed circuit board. The stationary structure **230** extends into the insulating wedge (dotted line **242**) and connects to the insulating wedge **210** through a large pin **232**. The large pin **232** extends through the stationary structure **230** and into a hole in the wedge **210** that is located at position **244**. When the large pin **232** is moved up out of the hole **244**, it breaks the connection between the insulating wedge **210** and the stationary structure **230**, and the insulating wedge is then free to move.

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A compression spring **234** applies vertical force on large pin **232**. Large pin **232** is prevented from moving by a small pin **240** that affixes the large pin to the stationary structure **230**. The small pin is held in place by the pressure of the compression spring **234** pushing on the large pin **232**. The small pin **240** can be displaced, thereby releasing the large pin **232**, by a pulling force from the shape memory alloy wire **226**. The shape memory alloy **226** is mechanically connected to a post **228** that in turn is rigidly connected to the stationary structure **230**. The shape memory alloy wire **226** is nominally made out of a nickel titanium (nitinol) alloy. When heated past a characteristic transition temperature, the molecular structure of the wire changes from a martensitic state to an austenitic state, causing the wire to contract in length. The wire can be heated internally by an electrical connection from the one shot control.

FIG. 14 gives an alternative view of the insulating wedge **210**. The stationary structure **230** may be assumed to be in a fixed position. The wedge **210** is attached to the slide **236** and back plate **238** and can move away from the stationary structure **230**. The wedge **210** and stationary structure **230** are held together by the large pin **232**. The compression spring **234** applies a force on the large pin **232** in a direction that would release the large pin **232** and allow the wedge **210** to separate from the stationary structure **230**. The large pin is released when a small pin (not shown) is pulled out of a retaining hole by a shape memory alloy wire **226**.

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FIG. 15 depicts a permanent wall outlet with a removable self-testing GFCI/AFCI component. The permanent outer shell **244** contains the outlets into which an appliance plug would be inserted. The GFCI and/or AFCI component **246** would contain both fault sensing electronics as well as self-testing electronics and the primary and secondary circuit breakers. When this removable component **246** is absent, or if either the primary or secondary circuit breakers within the removable component **246** are in an open state, the outlets in the permanent outer shell **244** are deenergized. The advantage to using this configuration is that in the case of a GFCI/AFCI malfunction, the outlet as a whole is easily repaired by simply replacing the removable component **246**. Note that while a test

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button 248 and reset button 250 are depicted in FIG. 15, they are unnecessary if the removable component 246 contains a self-testing circuit.

5 Although the invention has been described in detail with particular reference to these preferred embodiments, other embodiments can achieve the same results. Variations and modifications of the present invention will be obvious to those skilled in the art and it is intended to cover in the appended claims all such modifications and equivalents. The entire disclosures of all references, applications, patents, and publications cited above are hereby incorporated by reference.



## CLAIMS

What is claimed is:

- 5           1.       A self-testing fault interrupt apparatus comprising:
- a fault sensing component that detects an electrically unsafe operating condition;
- a primary electrical current interrupting component for preventing power delivery upon the detection of an electrically unsafe operating condition;
- 10               a fault sense testing component that automatically, and preferably periodically, disables the primary electrical current interrupting component, applies a simulated fault, verifies that the fault sensing component correctly detects this simulated fault, removes the simulated fault, and reenables the primary electrical current interrupting component if the fault sensing component correctly detected the simulated fault;
- 15               a circuit breaker testing component that, when the fault sensing component detects an electrically unsafe operating condition, automatically checks that the primary electrical current interrupting component has satisfactorily interrupted power delivery; and
- a secondary electrical current interrupting component that permanently removes power from the self-testing fault interrupt apparatus if the fault sense testing component
- 20               does not correctly detect a simulated fault or if the circuit breaker testing component determines that the primary electrical current interrupting component has not satisfactorily interrupted power delivery; and
- preferably wherein said apparatus is part of a fault-protection assembly not having manual test means; and
- 25               optionally wherein said apparatus is part of a fault-protection assembly comprising manual test means.

2. The apparatus of Claim 1 wherein said fault sensing component detects a ground fault, and preferably wherein said fault sense testing component simulates a ground fault by imposing an electrical leakage path around a current sense transformer.

5 3. The apparatus of Claim 1 wherein said fault sensing component detects an arcing fault.

4. The apparatus of Claim 1 wherein said primary electrical current interruption means comprises a solenoidal relay, and preferably wherein said fault sense testing component disables the  
10 primary electrical current interrupting component by disabling an actuating solenoid on said solenoidal relay.

5. The apparatus of Claim 1 wherein said primary electrical current interruption means comprises a member selected from the group consisting of solenoidal relays, bimetallic thermal circuit  
15 breakers, thermal magnetic circuit breakers, piezoelectric acutuated circuit breakers, shape memory alloy circuit breakers, and circuit breakers employing a fusible link.

6. The apparatus of Claim 1 wherein said secondary current interrupting component comprises a one shot circuit breaker.  
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7. The apparatus of Claim 1 wherein said secondary current interrupting component interrupts only one of two current carrying conductors.

8. The apparatus of Claim 1 wherein said secondary current interrupting component  
25 comprises a member selected from the group consisting of solenoidal relays, bimetallic thermal circuit breakers, thermal magnetic circuit breakers, piezoelectric actuated circuit breakers, shape memory alloy actuated circuit breakers, circuit breakers employing a fusible link, and circuit breakers employing a spring-loaded movable member released when a retaining resistance disintegrates upon

being energized.

9. The apparatus of Claim 1 wherein said secondary current interrupting component comprises conducting blades that are forced apart by an insulating wedge to interrupt power flow, and preferably wherein said insulating wedge is connected to a spring held in compression by a low wattage resistor, and most preferably wherein said spring is released when a high electrical current is passed through said low wattage resistor.

10. A self-testing fault interrupt method comprising the steps of:

10 a) detecting an electrically unsafe operating condition via a fault sensing component;

b) preventing power delivery upon the detection of an electrically unsafe operating condition via a primary electrical current interrupting component;

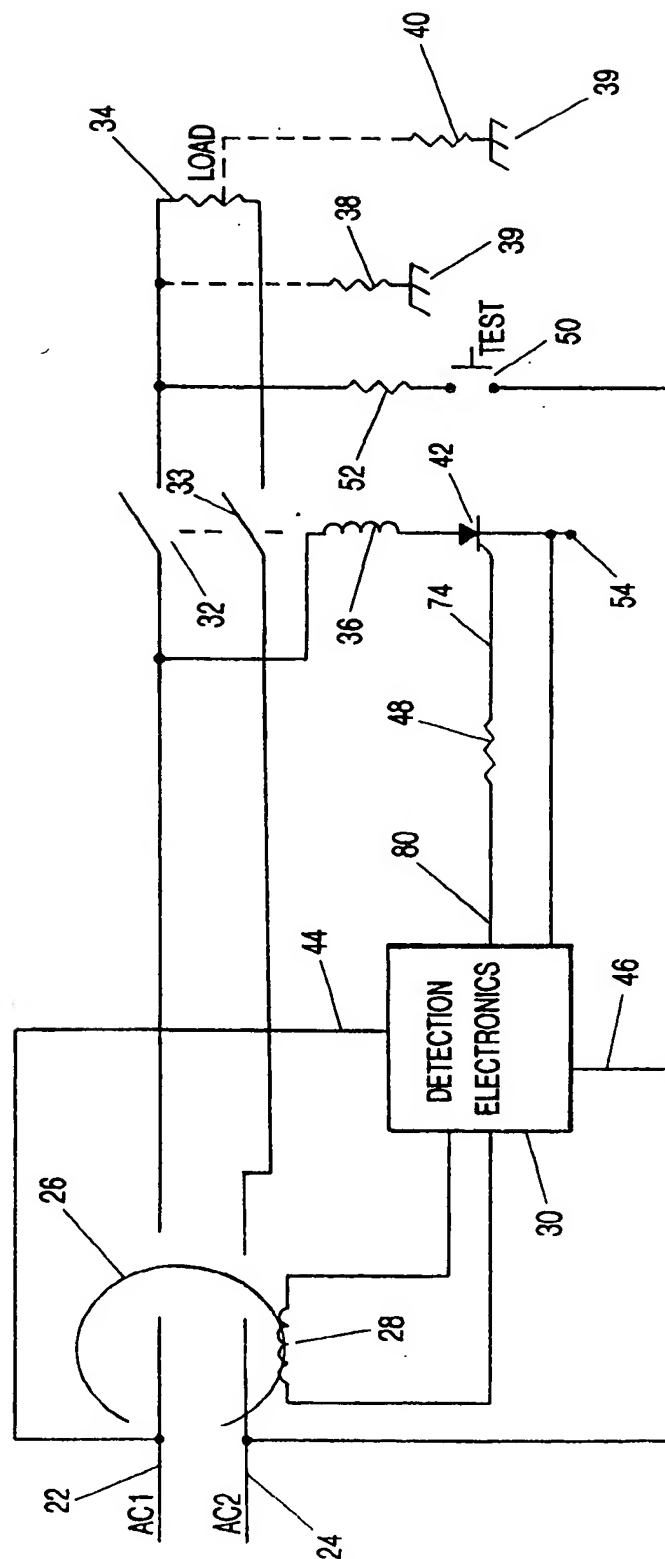
c) employing a fault sense testing component that automatically, and preferably periodically, disables the primary electrical current interrupting component, applies a simulated fault, verifies that the fault sensing component correctly detects this simulated fault, removes the simulated fault, and reenables the primary electrical current interrupting component if the fault sensing component correctly detected the simulated fault;

15 d) employing a circuit breaker testing component that, when the fault sensing component detects an electrically unsafe operating condition, automatically checks that the primary electrical current interrupting component has satisfactorily interrupted power delivery; and

20 e) employing a secondary electrical current interrupting component that permanently removes power from the self-testing fault interrupt apparatus if the fault sense testing component does not correctly detect a simulated fault or if the circuit breaker testing component determines that the primary electrical current interrupting component has not satisfactorily interrupted power delivery.

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**FIG-1**

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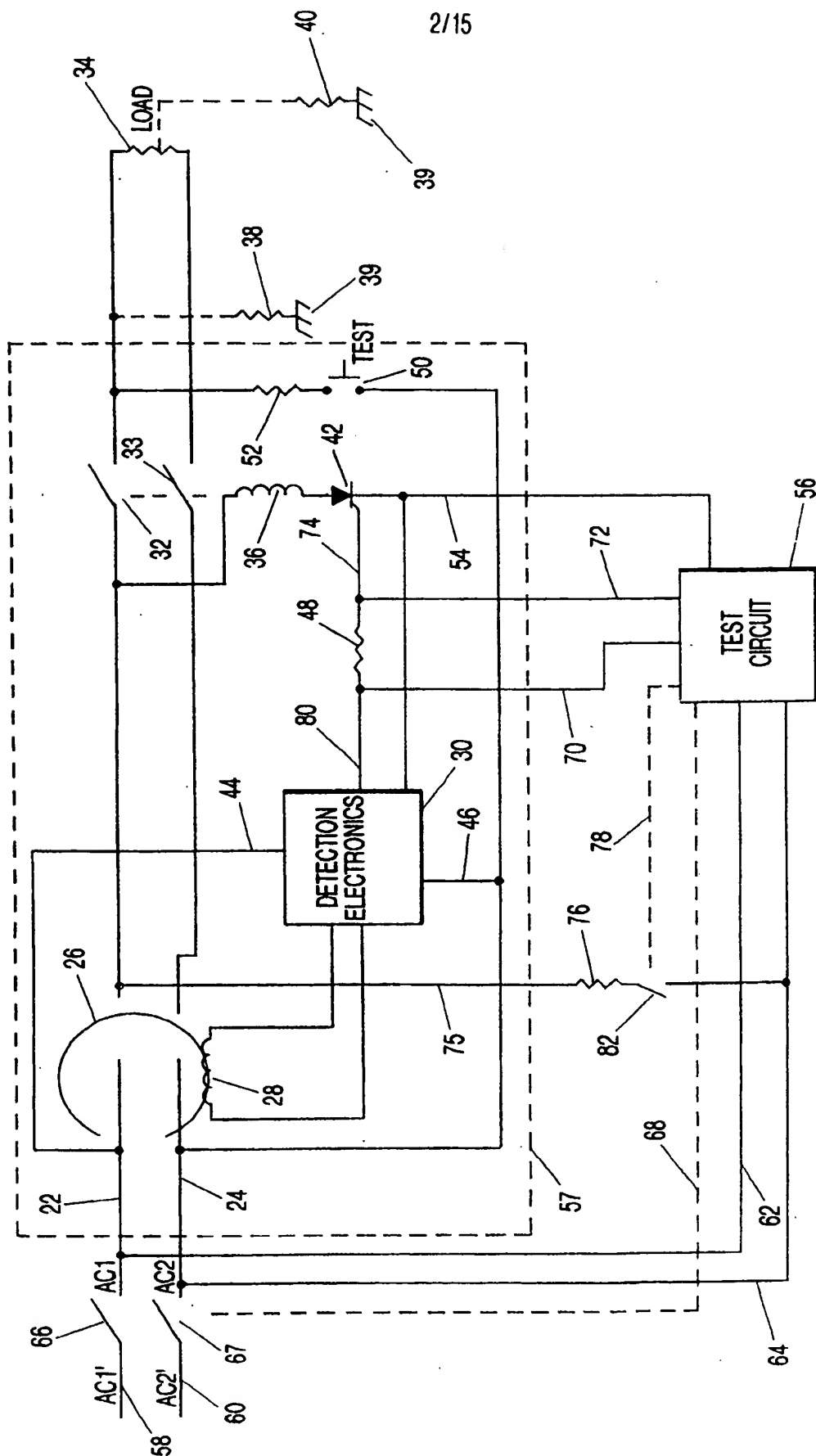


FIG-2

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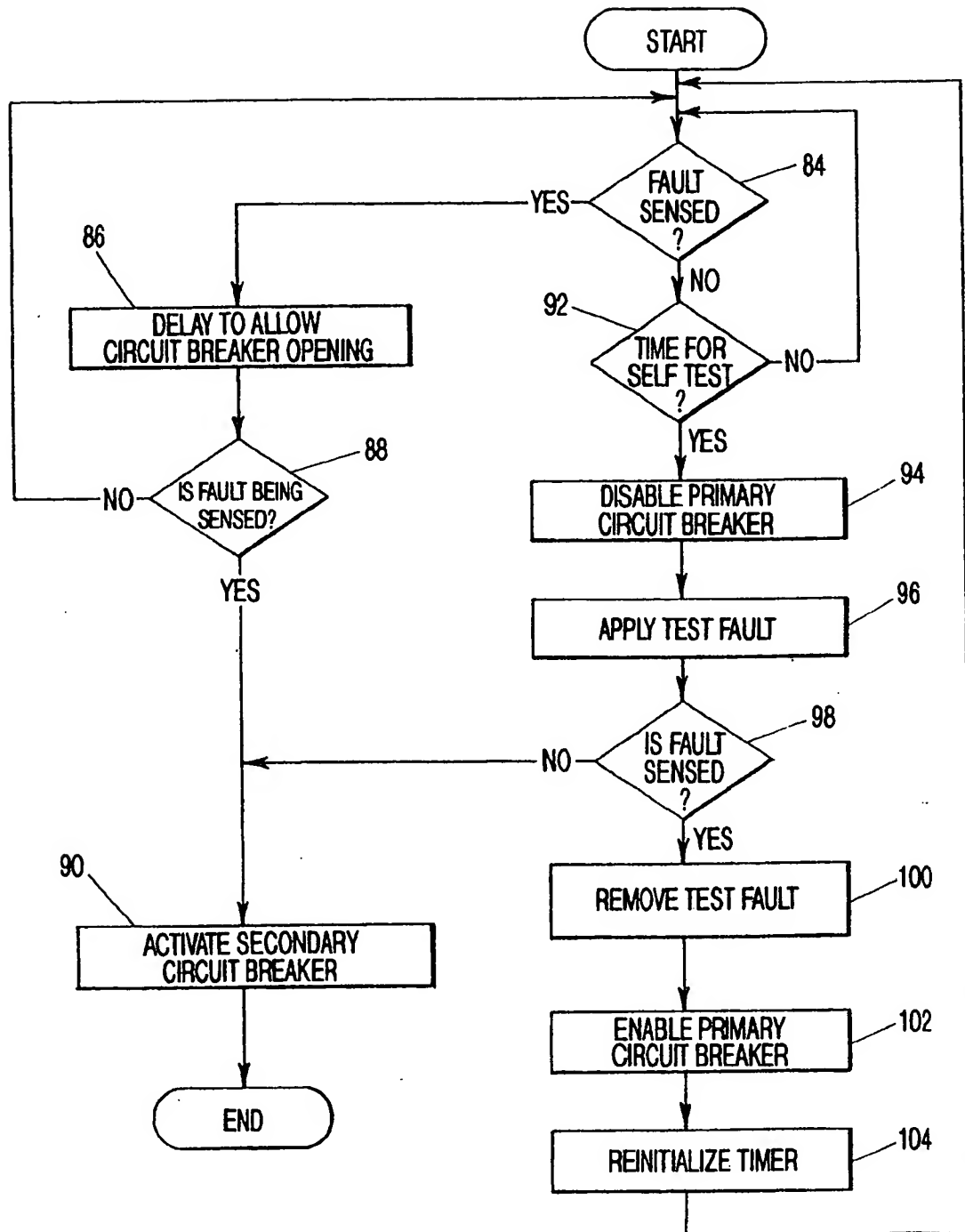


FIG-3

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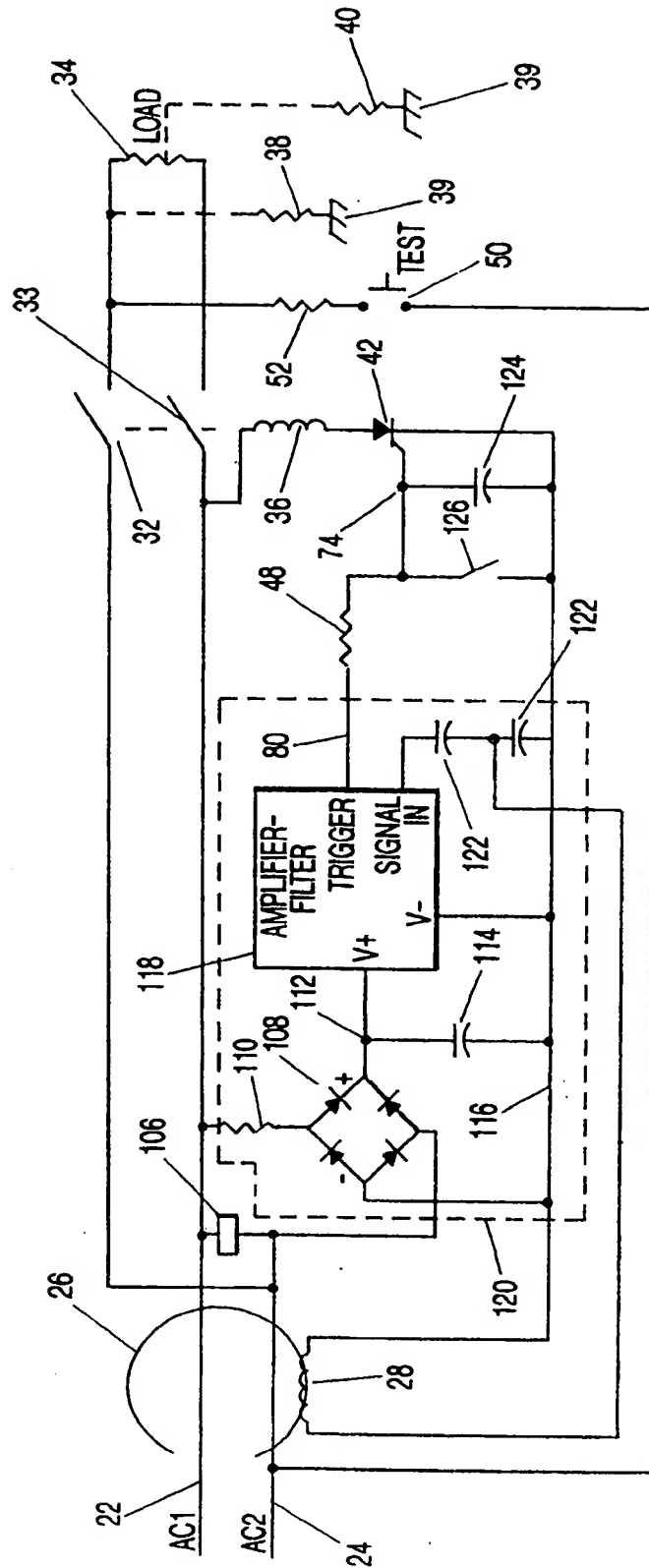


FIG-4

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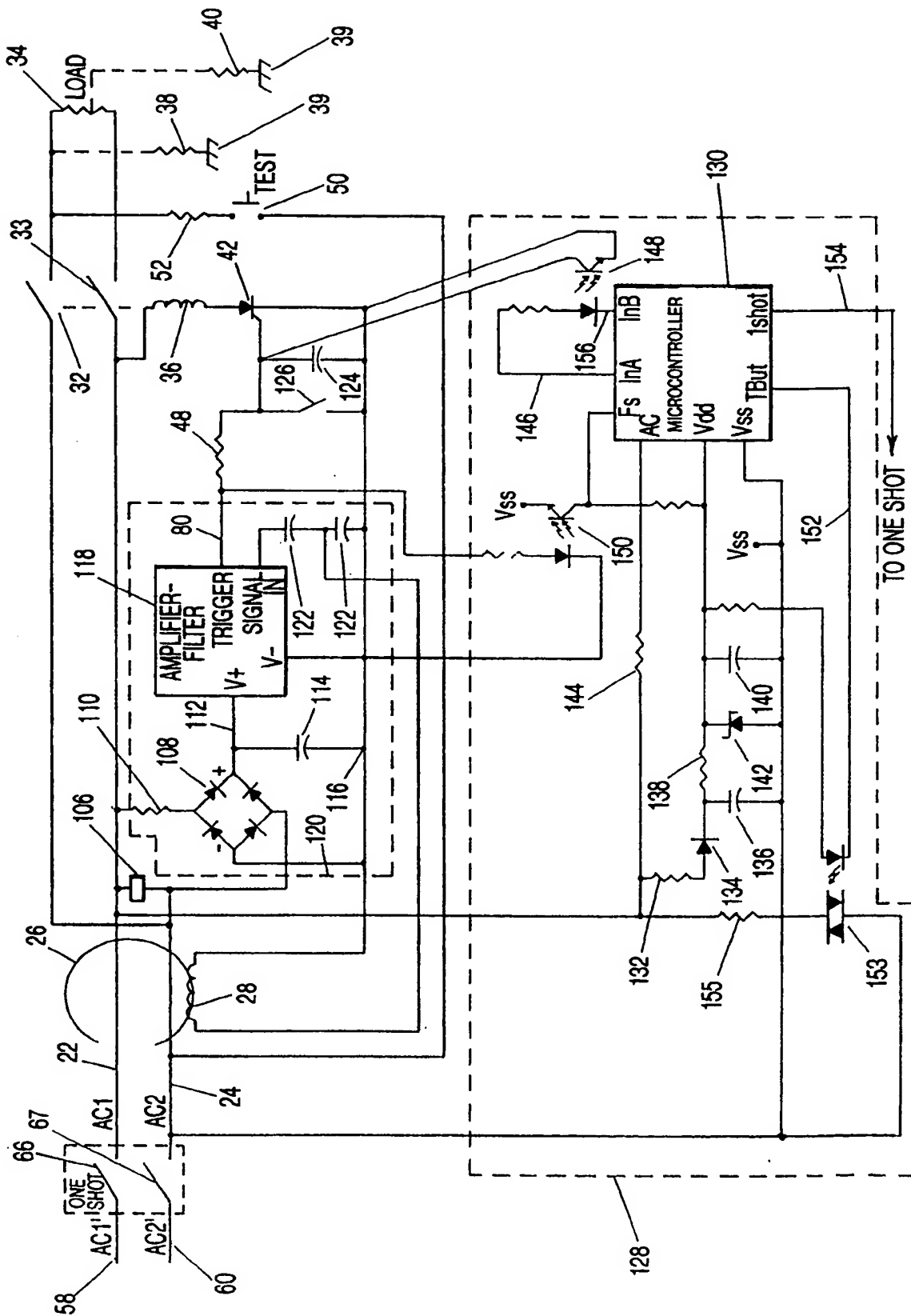


FIG-5



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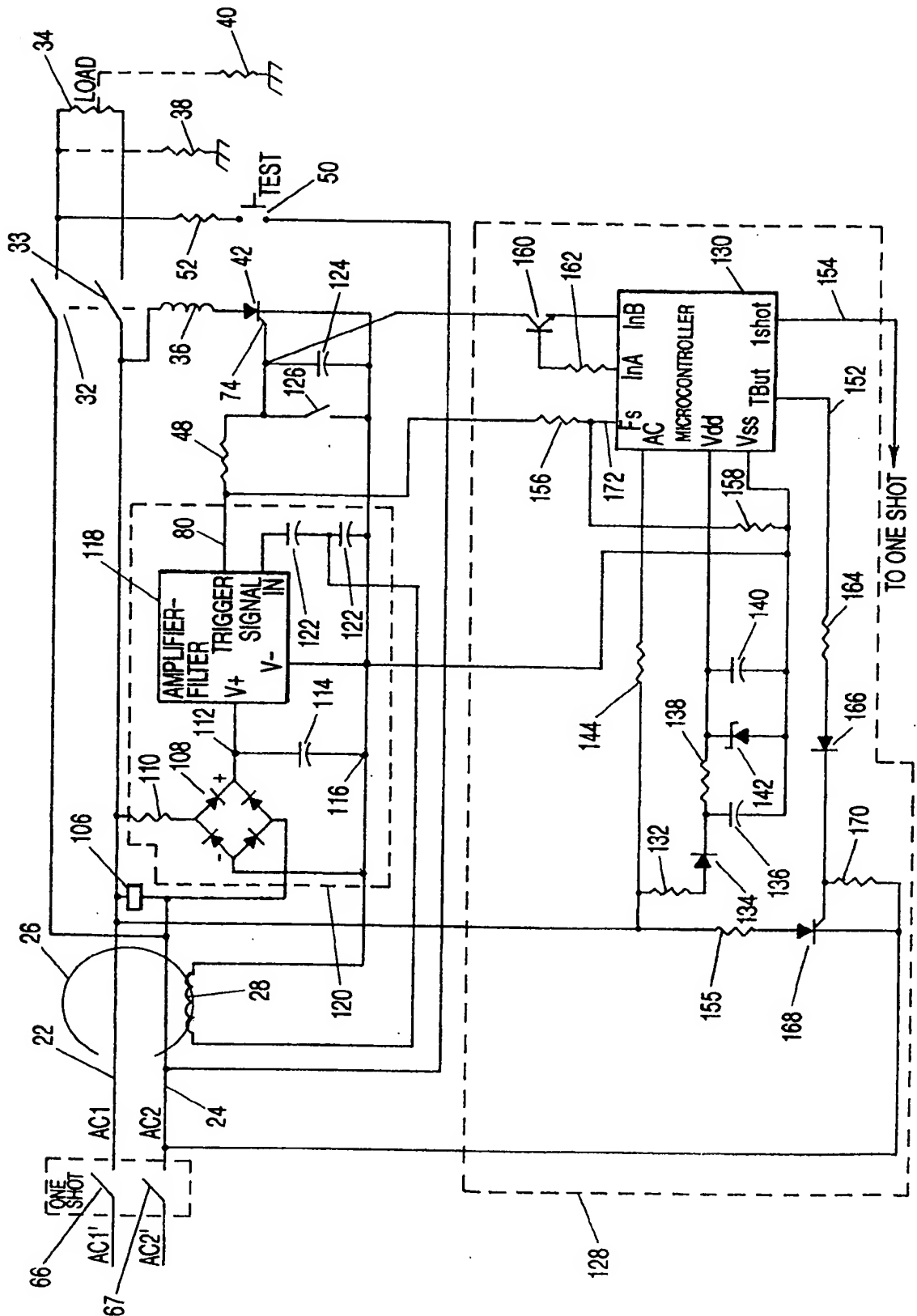


FIG-6

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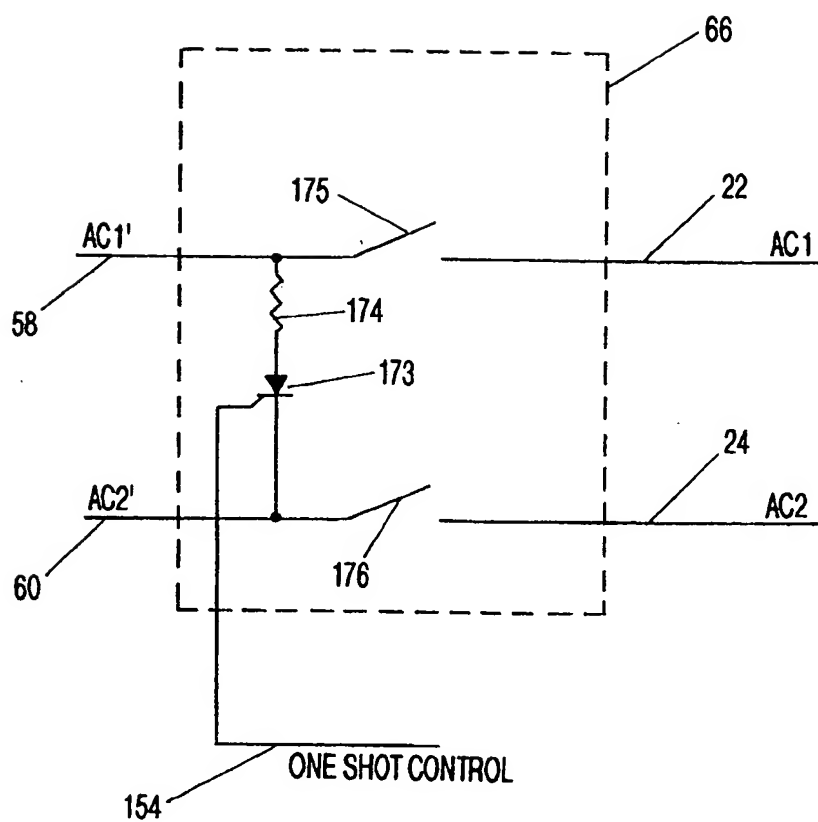


FIG-7

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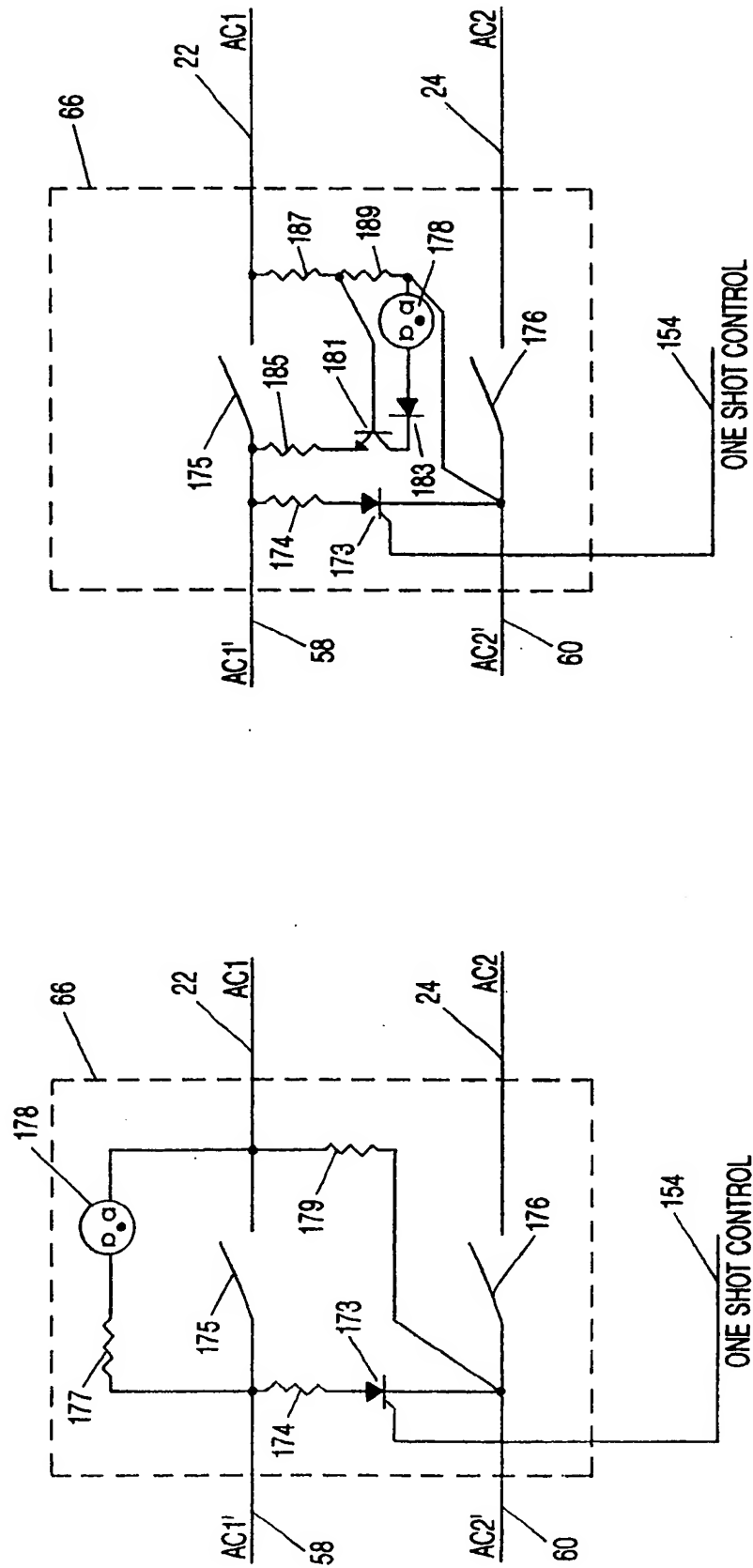


FIG-8b

FIG-8a

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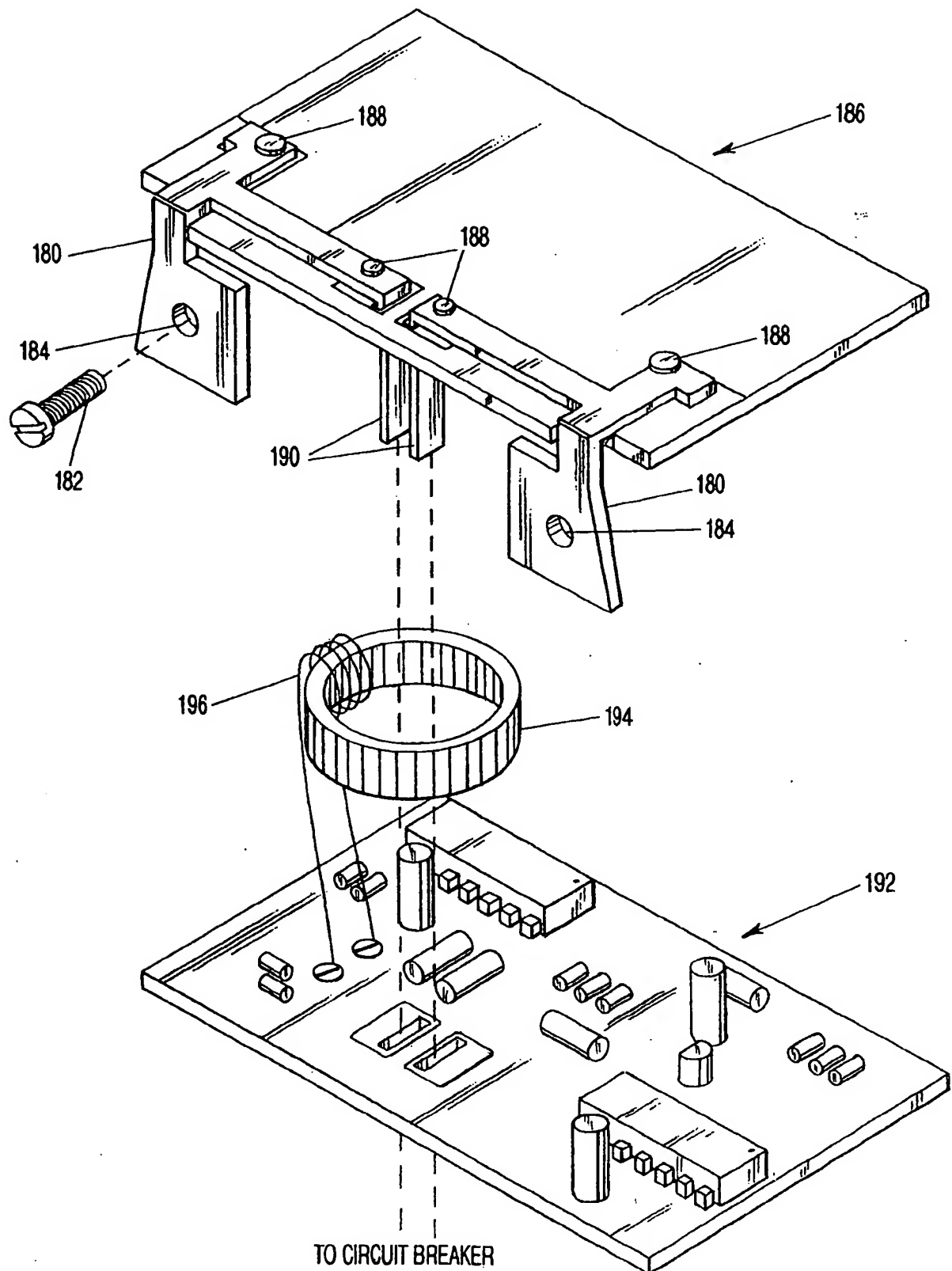


FIG-9

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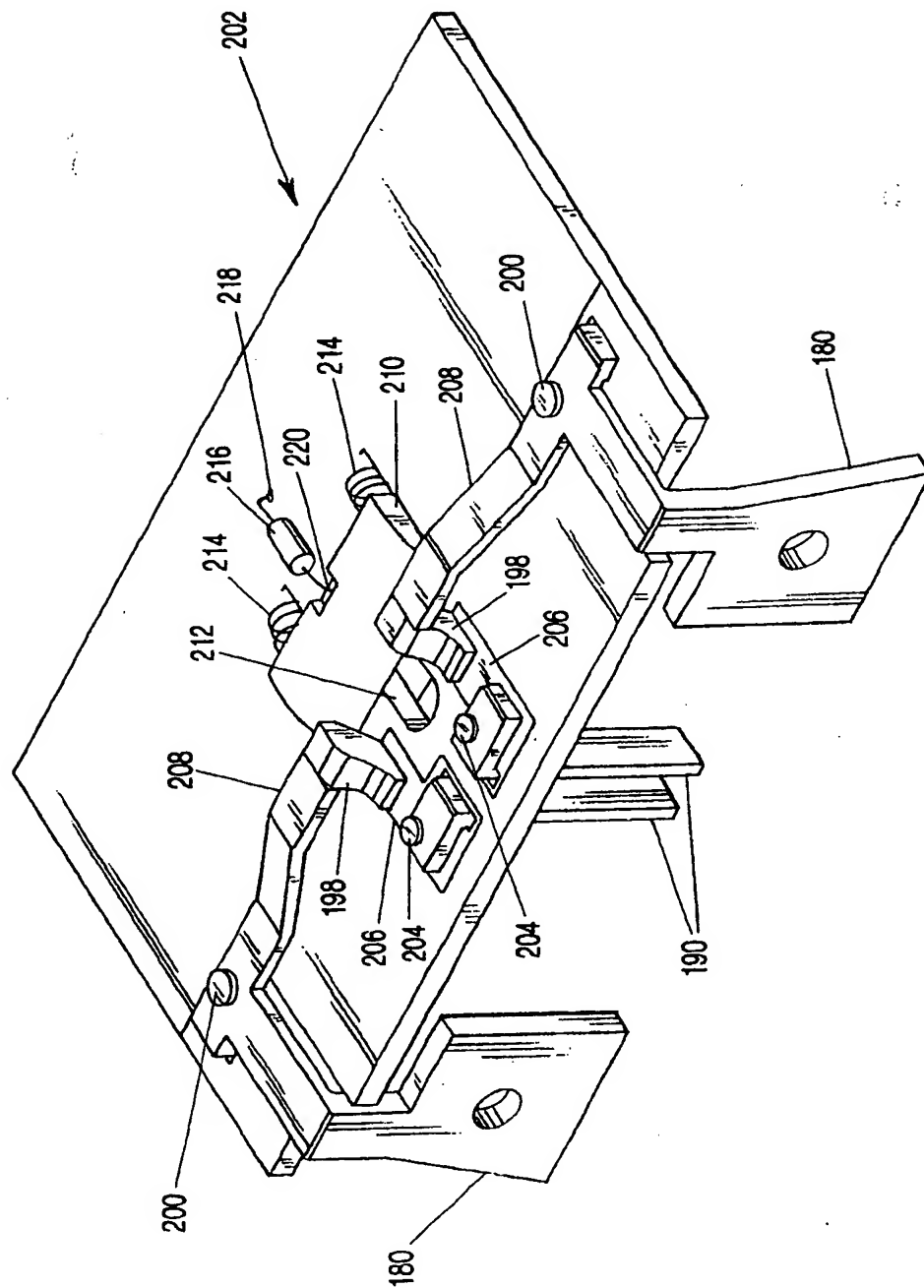


FIG-10

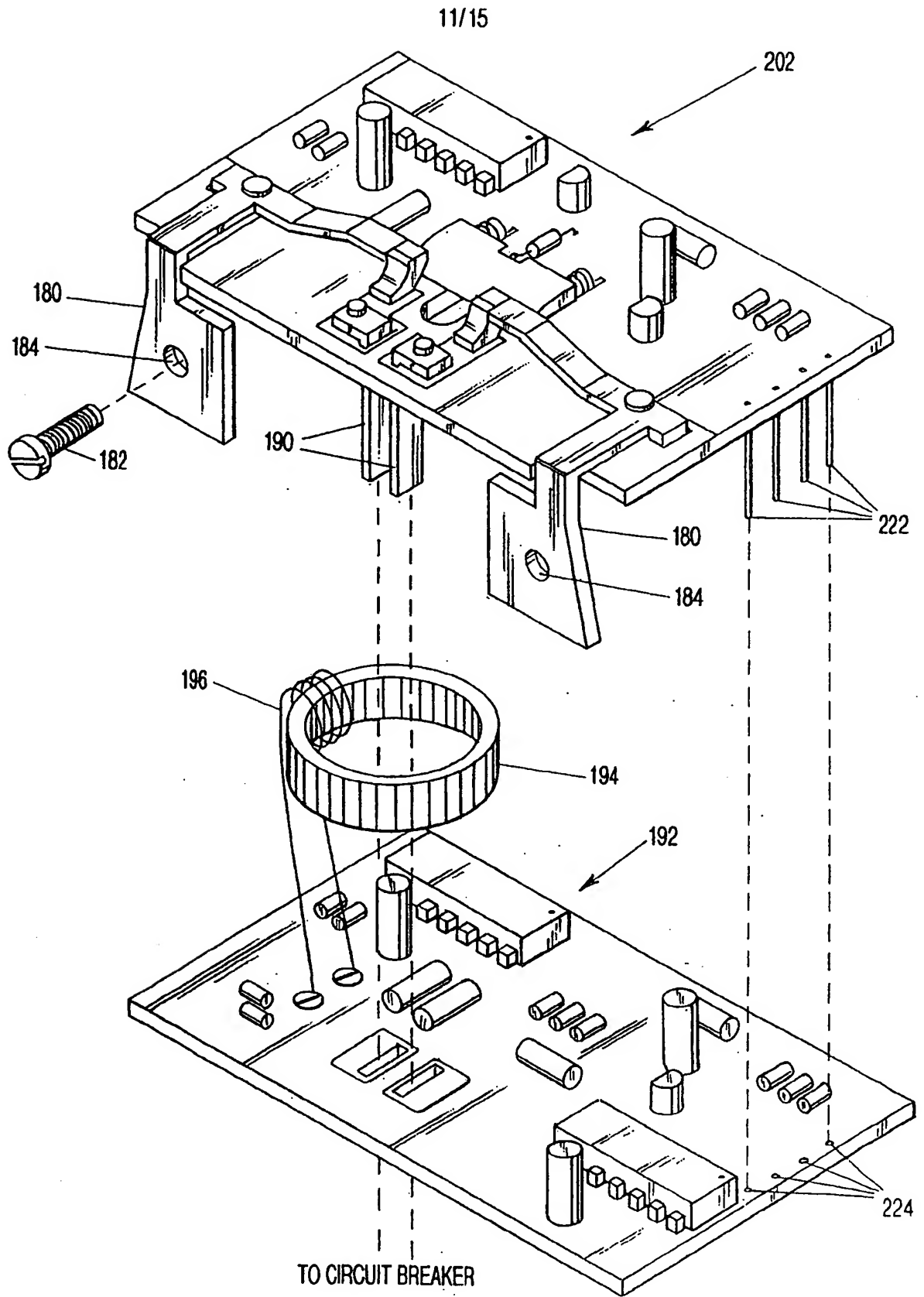
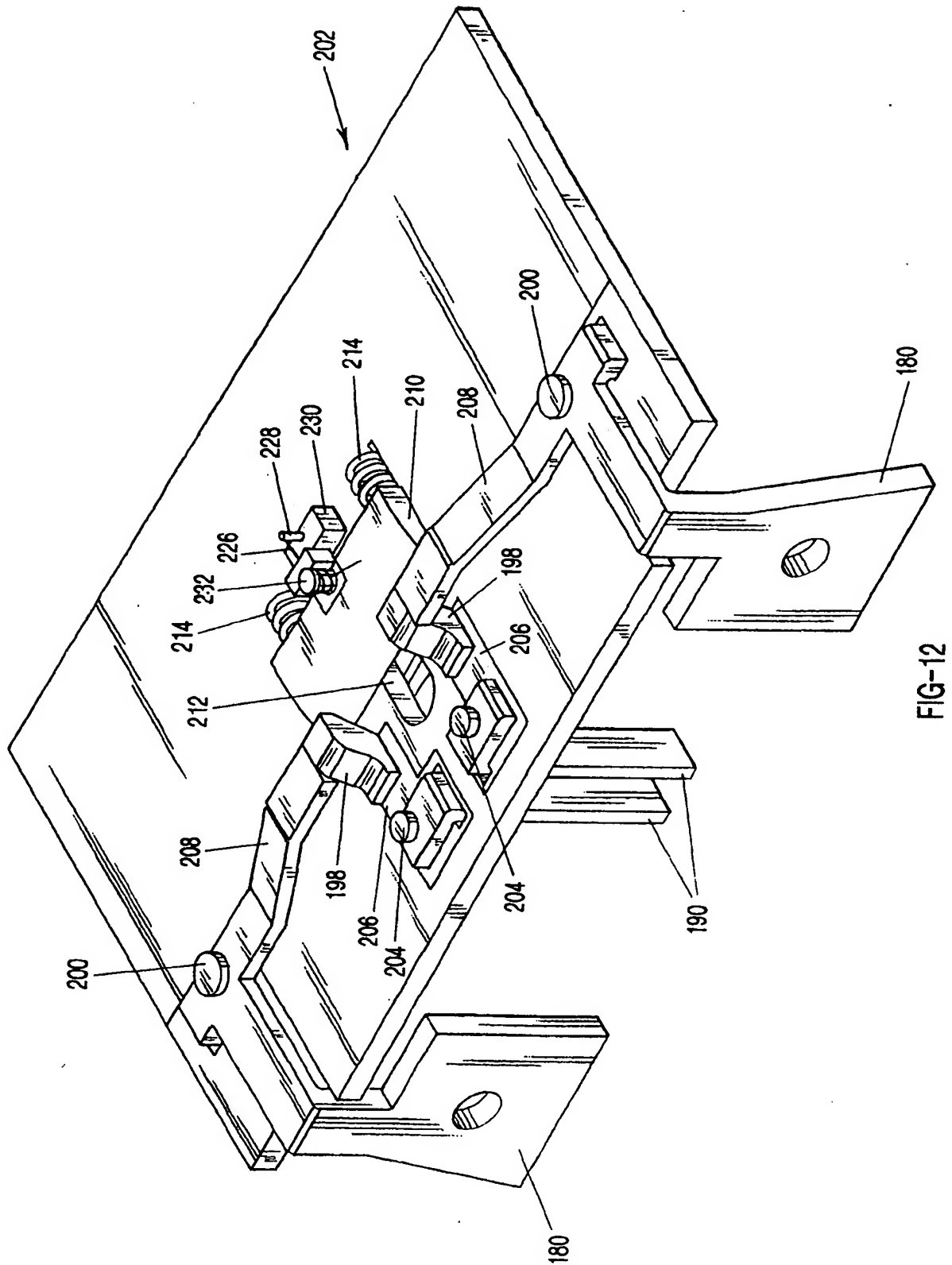


FIG-11

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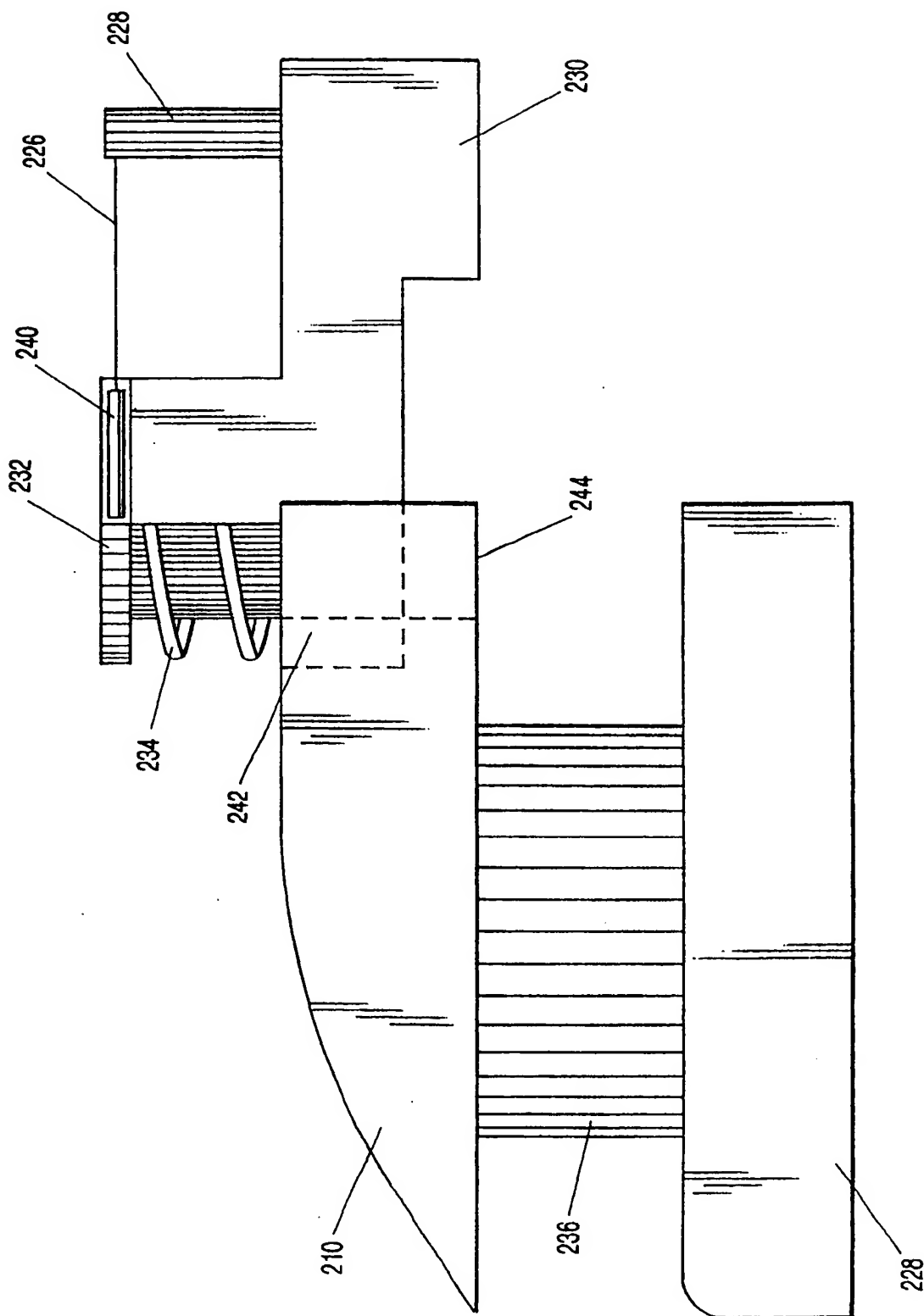
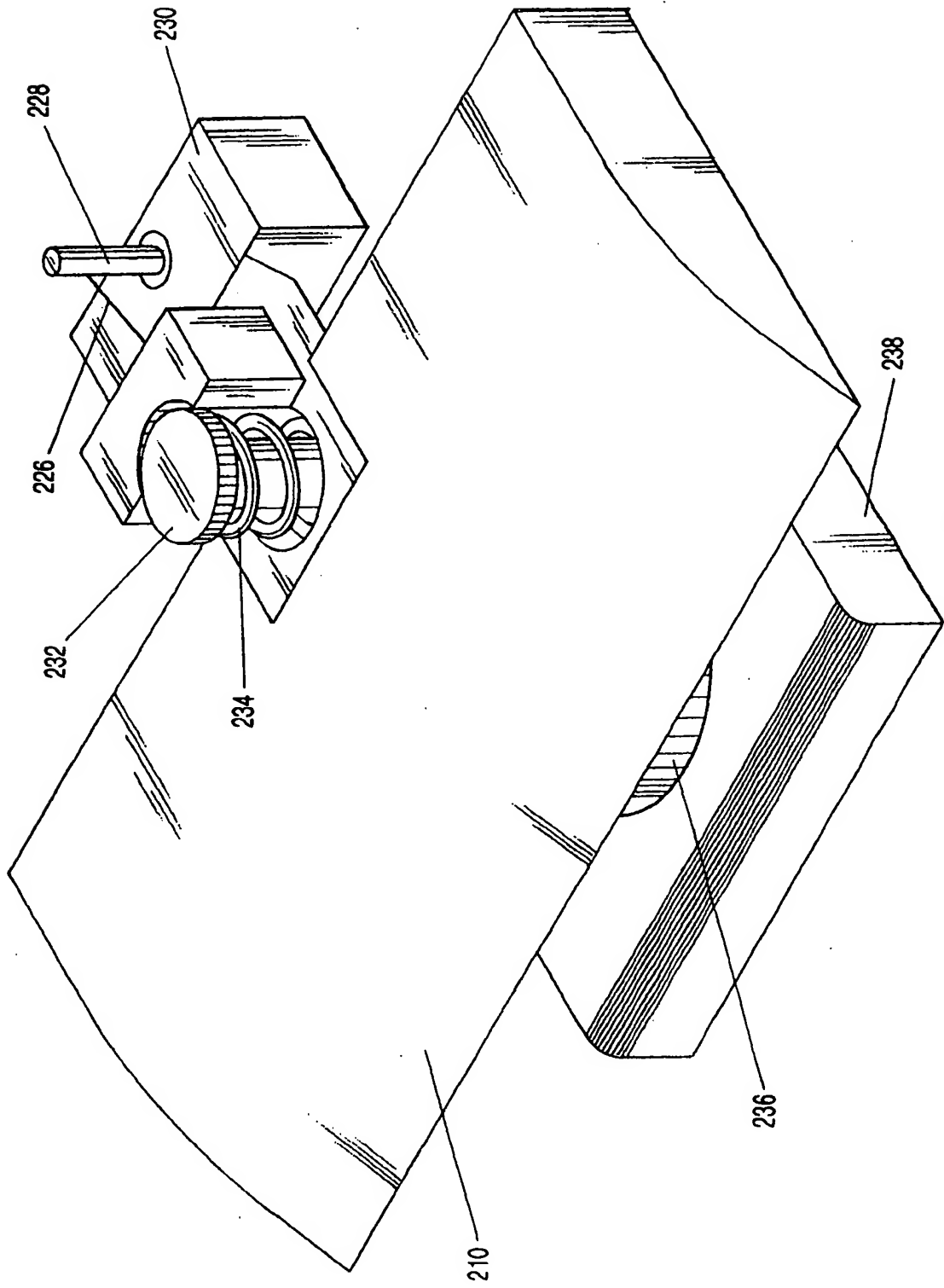


FIG-13



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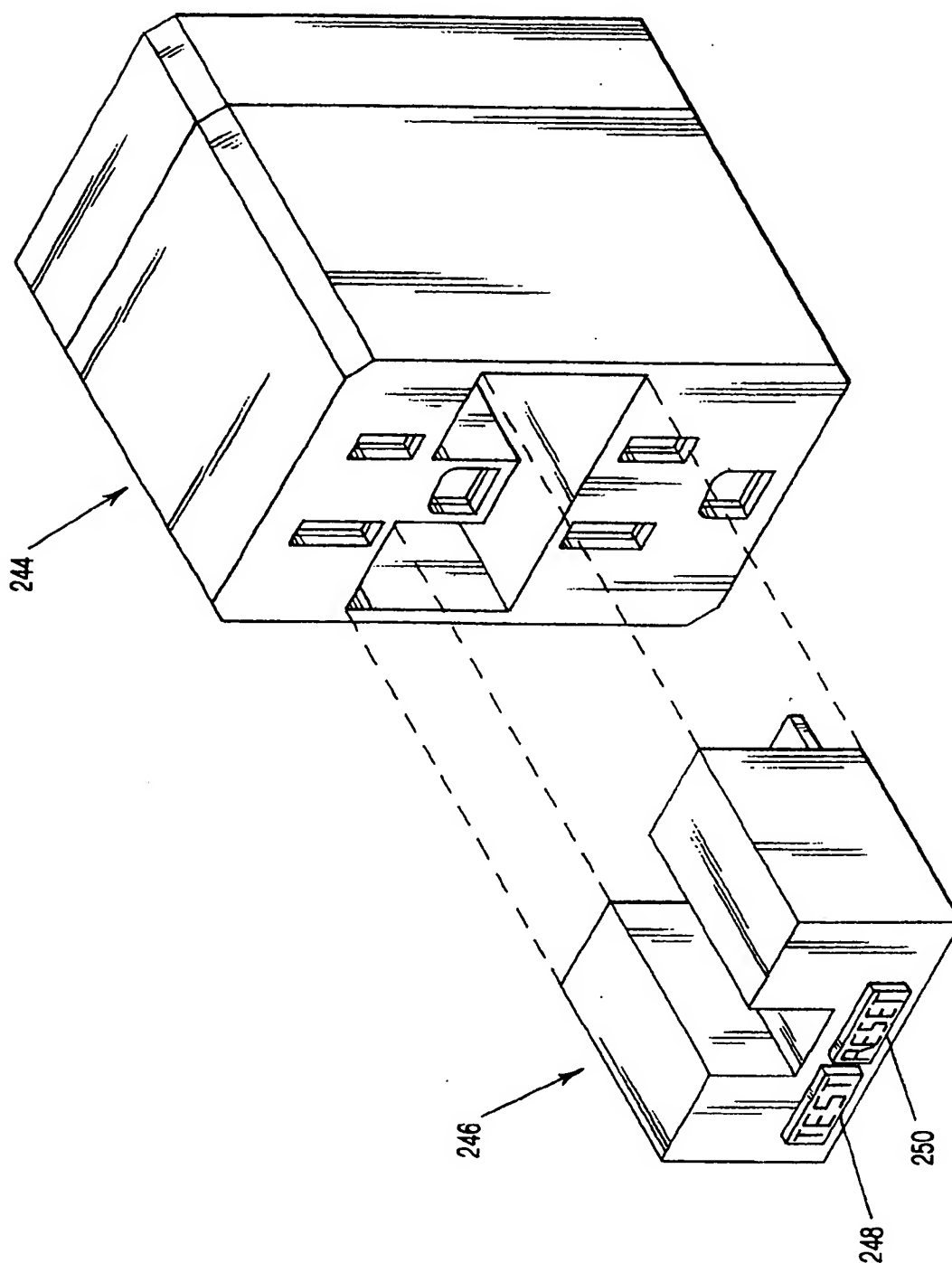


FIG-15

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/14824

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(7) : H02H 3/00; G01R 31/02  
US CL : 361/42-50; 324/418, 423, 424, 522, 523, 527-529

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 361/42-50; 324/418, 423, 424, 522, 523, 527-529

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,742,422 A (Tigges) 03 May 1988 (03.05.1988), Figure 1, Column 3, line 37 through Column 4, line 41, Column 5, line 17 through Column 6, line 56.	1-10
Y	US 4,031,431 A (Gross) 21 June 1977 (21.06.1977), Column 4, lines 3-8, Column 6, lines 6-20.	1-8 and 10
Y	US 4,540,859 A (Lemmer) 10 September 1985 (10.09.1985), Figures 3-9.	9

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

24 July 2000 (24.07.2000)

Date of mailing of the international search report

04 AUG 2000

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